

Steel Framing Prototype Development: Final Report



PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the next generation of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's homes.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, all federal agencies that engage in housing research and technology development are PATH partners, including the departments of Energy and Commerce, as well as the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA). State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH partnership.

To learn more about PATH, please contact:



451 7th Street, SW, Room 8134
Washington, DC 20410-0001
(800) 245-2691 ext. 2
email: pathnet@pathnet.org

Visit PD&R's Web Site

www.huduser.org

to find this report and others sponsored by

HUD's Office of Policy Development and Research (PD&R).

Other services of HUD USER, PD&R's Research Information Service, include listservs;

special interest, bimonthly publications (best practices, significant studies from other sources);

access to public use databases; hotline 1-800-245-2691 for help accessing the information you need.

Steel Framing Prototype Development: Final Report

Prepared in cooperation with:

U.S. Department of Housing and Urban Development

Affordable Housing Research and Technology Division

451 7th Street S.W.

Washington, DC 20410

Submitted by:

Manufactured Housing Research Alliance

2109 Broadway, Suite 200

New York, NY 10023

(212) 496-0900

December 2003

ACKNOWLEDGMENTS

This document was prepared by the Manufactured Housing Research Alliance (MHRA) with funding from the U.S. Department of Housing and Urban Development and the North American Steel Framing Alliance. In coordination with other project sponsors, MHRA appoints a project steering committee to oversee individual research efforts. MHRA staff, contractors, and industry advisors assist the steering committee. The following individuals participated in the development of this document:

Rick Boyd, Clayton Homes, Inc., **Chairman**
Frederic Berg, Quality Homes of the Pacific, LLC
Michael Blanford, U.S. Department of Housing and Urban Development
Ed Bryant, Champion Enterprises
Randy Cosby, R-Anell Housing Group, LLC
Courtney Hanson, Nucor Steel
Gary Johnson, Fleetwood Enterprises
Dennis Jones, R-Anell Housing Group, LLC
Donald Moody, Nucor Steel
Mark Nunn, Manufactured Housing Institute
Robert (Pat) Patterson, Quality Homes of the Pacific, LLC
Alex Toback, Toback and Associates
Kali Watson, Quality Homes of the Pacific, LLC
Larry Williams, North American Steel Framing Alliance
Harold Woodside, R-Anell Housing Group, LLC

Project coordination staff and contractors
Jordan Dentz, Manufactured Housing Research Alliance
Sandra Ho, Manufactured Housing Research Alliance
Jeffrey Klaiman, ADTEK Engineers, Inc.
Emanuel Levy, Manufactured Housing Research Alliance
Dean Peyton, Anderson-Peyton
Chris St. Clair, Steel Truss Systems
Ray Tucker, RADCO, Inc
Jim Walfish, P.E.

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

While the information in this document is believed to be accurate, neither the authors nor reviewers, the U.S. Department of Housing and Urban Development, the Manufactured Housing Research Alliance, the North American Steel Framing Alliance, nor any of their employees or representatives, makes any warranty, guarantee, or representation, expressed or implied, with respect to the accuracy, effectiveness, or usefulness of any information, method, or material in this document, nor assumes any liability for the use of any information, methods, or materials disclosed herein, or for damages arising from such use. This publication is intended for the use of professional personnel who are competent to evaluate the significance and limitations of the reported information and who will accept responsibility for the application of the material it contains. All responsibility as to the appropriate use of information in this document is the responsibility of the reader or user.

The contents of this report are the view of the contractor and do not necessarily reflect the views or policies of the U.S. Department of Housing and Urban Development or the U.S. government.

The U.S. government does not endorse products or manufacturers. Trade names or manufacturer names that appear herein are used solely because they are considered essential to the objective of the report.

About the Manufactured Housing Research Alliance

The Manufactured Housing Research Alliance (MHRA) is a non-profit organization with the mission of developing new technologies to enhance the value, quality, and performance of the nation's manufactured and modular homes. Research conducted by MHRA supports the industry by developing new methods for using factory built homes in a wide array of housing applications; solving technical challenges; and paving the way for innovations in home design, construction, and installation.

To carry out its mission, MHRA develops, tests, and promotes better methods and materials for designing, manufacturing, and marketing factory built homes. These activities include research, new product development, training and educational programs, testing programs and demonstrations, commercialization efforts, workshops, conferences, and other events.

MHRA has over 400 members who build, supply materials for, sell, develop, and finance more than 80 percent of all new manufactured homes.

TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Objective	1
1.2	Steel use in residential construction	2
1.3	Previous research.....	4
1.4	Structure of this report.....	5
2	CASE STUDY: QUALITY HOMES OF THE PACIFIC	6
2.1	Background	6
2.2	Objectives of the work with QHP.....	7
2.3	First-generation designs.....	8
2.4	Second-generation design.....	14
2.5	Summary of second-generation design changes.....	33
2.6	Suggested next steps.....	35
3	CASE STUDY: R-ANELL HOUSING GROUP, LLC	36
3.1	Objectives of the work with R-Anell.....	36
3.2	General design criteria.....	37
3.3	Design development	38
3.4	Suggested next steps.....	45
	APPENDIX A R-ANELL DRAWINGS	47
	APPENDIX B RESOURCES	73

LIST OF TABLES AND FIGURES

Table 2-1 Summary of QHP design changes.....	34
Figure 2-1 The Quality Homes of the Pacific plant.....	6
Figure 2-2 The QHP production line.....	8
Figure 2-3 Steel chassis being welded on the production line	9
Figure 2-4 Tires are inset into the chassis	9
Figure 2-5 Steel studs and other components are produced in the plant	9
Figure 2-6 Assembled steel roof trusses.....	10
Figure 2-7 Roof assembly	10
Figure 2-8 Gypsum board applied to the ceiling	10
Figure 2-9 Home section prior to roof installation	11
Figure 2-10 Insulation being placed in assembled home section	11
Figure 2-11 Portion of framed home section showing cross-bracing and header	11
Figure 2-12 Cross-brace connection detail.....	11
Figure 2-13 Home sections in the finishing station.....	12
Figure 2-14 Installed home with attached garage.....	12
Figure 2-15 Installed home with wrap around porch	12
Figure 2-16 Steel roof truss (original design).....	15
Figure 2-17 Steel roof assembly sequence (original design).....	15
Figure 2-18 Roof trusses being connected to the ceiling board.....	16
Figure 2-19 Trusses and assembled home sections	16
Figure 2-20 Typical truss and joint stud alignment (original design)	16
Figure 2-21 Truss rafter and ceiling panels (original design).....	18
Figure 2-22 The eave overhang with soffit vent.....	18
Figure 2-23 Connection of the truss to the wall studs	18
Figure 2-24 Eave detail with non-structural top track (revised design)	19
Figure 2-25 Eave detail with structural wood top plate (revised design).....	20
Figure 2-26 Eave detail with structural light-gauge steel box track (revised design)	20
Figure 2-27 Eave detail with non-structural track and metal roof truss (revised design).....	21
Figure 2-28 Ridge line pony wall and continuous beam (original design).....	22
Figure 2-29 View into the roof cavity showing the box ridge beam	22
Figure 2-30 Ridge (original design)	23
Figure 2-31 Split girder truss ridge beam (revised design)	23
Figure 2-32 Typical X-brace isometric (original design).....	24
Figure 2-33 Floor plan showing shear walls (original design).....	25
Figure 2-34 Typical X-brace top (original design).....	25
Figure 2-35 Cross-bracing with reduced number of screws (revised design)	26
Figure 2-36 Hardy Frame wall track	27
Figure 2-37 Exterior wall-to-floor joist connection (original design)	28
Figure 2-38 C channel floor detail (revised design).....	29
Figure 2-39 HSS chassis beam with Dietrich floor system (revised design)	29
Figure 2-40 Top of floor decking in same plane as top of chassis channel.....	30

Figure 2-41 Detail of wall framing at chassis edge.....	30
Figure 2-42 Typical wall-to-floor strap (original design)	30
Figure 2-43 Isometric view of interior (original design).....	31
Figure 2-44 Foundation to sidewall connection (original design).....	31
Figure 2-45 Wall anchor plate detail (revised design)	32
Figure 2-46 Seven different screw types used in the plant.....	32
Figure 2-47 Framing at window showing welds, header, and stud-truss alignment	33
Figure 2-48 Welded studs at window opening	33
Figure 3-1 Building section	38
Figure 3-2 Roof truss section	39
Figure 3-3 Typical overbuild frame detail.....	40
Figure 3-4 Typical section at side wall.....	41
Figure 3-5 Section at marriage wall	42
Figure 3-6 First floor wall framing plan.....	43
Figure 3-7 Typical floor bracing detail	44
Figure 3-8 Typical rim joist connection detail	44
Figure 3-9 Typical detail at foundation edge.....	44
Figure A-1 First floor framing plan.....	51
Figure A-2 First floor wall framing plan.....	52
Figure A-3 Second floor framing at truss bottom chord	53
Figure A-4 Second floor wall framing plan.....	54
Figure A-5 Roof framing plan at truss top chord	55
Figure A-6 Building section	56
Figure A-7 Building section at front gable.....	56
Figure A-8 Typical section at side wall.....	57
Figure A-9 Section at marriage wall	58
Figure A-10 Typical section at gable end.....	59
Figure A-11 Dormer section.....	60
Figure A-12 Dormer plan	60
Figure A-13 Dormer section (detail)	61
Figure A-14 Opening elevation at dormer.....	61
Figure A-15 Typical track-to-stud connection detail	62
Figure A-16 Typical corner wall details.....	62
Figure A-17 Typical stud and rafter bridging details	63
Figure A-18 Typical unsupported track splice detail	63
Figure A-19 Typical bulkhead connection detail	63
Figure A-20 Typical connection detail.....	64
Figure A-21 Typical box beam detail.....	64
Figure A-22 Typical beam connection detail	64
Figure A-23 Typical floor bracing detail.....	65
Figure A-24 Typical rim joist connection detail	65
Figure A-25 Typical roof truss connection detail.....	66
Figure A-26 Typical foundation edge detail	66
Figure A-27 Typical detail at pier	66
Figure A-28 Typical rim beam splice detail.....	67
Figure A-29 Typical overbuild frame detail.....	67
Figure A-30 Optional wood truss connection detail.....	68
Figure A-31 Typical truss connection detail	68
Figure A-32 Typical truss bridging details.....	68
Figure A-33 Typical truss connection detail	69
Figure A-34 Typical truss connection detail	69

Figure A-35 Typical exterior light-gage bearing stud elevation at opening.....	70
Figure A-36 Typical interior light-gage bearing stud elevation at opening	70
Figure A-37 Alternate jamb details	71
Figure A-38 Typical bearing wall opening section	71
Figure A-39 Header to jamb connection detail	72
Figure A-40 Truss section	72

1

INTRODUCTION

1.1 OBJECTIVE

The use of light-gauge steel framing as a structural framework for residential construction has taken hold in some site-built markets but potentially offers even more value in the manufactured housing environment. Steel is lightweight, fire-resistant, dimensionally stable, and can be manufactured to any size or shape. When used by properly trained manufacturing plant personnel in a manner that takes advantage of its structural properties, steel may offer some compelling economic advantages over wood as a framing material.

The research effort described in this report explores the potential of steel framing for the construction of factory built homes that conform to the U.S. Department of Housing and Urban Development (HUD) code, or the International Residential Code (IRC), with the goal of developing technologies that are competitive with wood framing. This research critically assesses and refines the use of light-gauge steel design in the factory environment. MHRRA first explored the use of light-gauge steel for factory building in 2001 when developing a design intended to demonstrate the economic and regulatory viability of steel for HUD-code construction. The current work builds on this earlier effort by exploring the commercial viability of light-gauge steel-frame designs through a case study approach conducted in cooperation with industry partners.

The objectives of this research tightly mesh with the goals of HUD's "Partnership for Advancing Technology in Housing" (PATH), the overall mission of which is to improve the affordability and value of America's homes through technology, including the development of new housing technologies. Steel framing of factory built homes has the potential to improve home durability, quality, affordability, and resistance to natural disaster damage, and to reduce their environmental impact.

An earlier phase of steel framing research (completed in 2002¹) demonstrated that steel is an acceptable framing material under the performance-based HUD standards. The HUD certification of a plant featured in one of the case studies, Quality Homes of the Pacific (QHP) in Hawaii, reinforces this point. While many in the manufactured housing industry are cautiously optimistic about steel framing, it is recognized that numerous technical and economic issues remain to be resolved and that steel framing will most likely start as a niche technology for factory built housing. The objective of the Phase II research was to develop steel framing to the point of viability as a technology that can offer advantages consistent with the PATH goals. As an alternative to wood, steel can help keep housing costs down, particularly if wood costs rise or in inner-city locations where wood framing is not permitted.

¹ *Design for a Cold Formed Steel Framed Manufactured Home: Technical Support Document*, Manufactured Housing Research Alliance, 2002.

1.2 STEEL USE IN RESIDENTIAL CONSTRUCTION

Sheet metal is the base material for steel framing. Sheet steel is readily transformed into shapes used for framing and galvanized to prevent corrosion. The primary framing member shapes in residential construction are the C-shaped stud and joist and the U-shaped track. Steel framing members are typically manufactured at thicknesses of between 24- and 14-gauge.² These pieces can be cut with a chop saw, aviation snips, or electric shears.

Steel framing members meet nationally established standards of strength, consistency, and dimensional stability, and are manufactured throughout the country. Each manufacturer typically has a network of distributors that sell directly to builders. An increasing number of building suppliers also stock steel framing.³

When used in site-built or conventional home construction, steel-framing members typically substitute one-for-one for wood-framing members in both non-load-bearing and load-bearing applications. The C-shaped steel pieces—studs, joists, and rafters—fit into U-shaped top and bottom steel tracks.

All major building codes allow structural steel framing. The Council of American Building Officials (CABO), in the *CABO One and Two Family Dwelling Code*, and the International Residential Code (IRC 2000) specify methods for residential use of steel framing. These methods prescribe stud sizing and spacing, joist and rafter spans, fastener schedules, and construction details. In locales that adopt these codes, the application of the prescribed methods permits construction of site-built steel-framed houses without the certification of a professional engineer. In other areas, or if the prescriptive methods are not endorsed by local code bodies, a professional engineer may be required to design, review, and seal plans.

In 2001, more than 50,000 new housing units in the United States used steel framing as their primary structural material for walls.⁴ The vast majority of these homes were site built. Steel framing has been used far less for modular construction and until this effort, steel was not used for HUD-code homes.

Steel framing can potentially provide many benefits for factory built residential housing. The many benefits enumerated by the steel industry include:⁵

- Steel framing members are consistently straight and square, resulting in straight walls and square corners. This eliminates the need to cull or sort through a pile of studs of varying quality. The consistent material quality is a result of production in strict accordance with national standards.
- Pre-punched holes in the framing members simplify the installation of electrical wiring and plumbing.
- Because steel can be roll-formed in the plant and/or ordered to specific lengths, less scrap and waste is produced. The waste generated is 100 percent recyclable, and the framing members themselves contain up to 28 percent recycled material.

² Steel thickness increases as gauge size decreases.

³ See <http://www.toolbase.org/tertiaryT.asp?TrackID=andDocumentID=2037andCategoryID=1024>

⁴ See <http://www.steel framing alliance.com/dispatch.php?what=displayHome>

⁵ See http://www.toolbase.org/docs/MainNav/SteelFraming/2898_WhatAboutSteelFramingBrochure.pdf

- Steel is up to two-thirds lighter than other framing materials and has the highest strength-to-weight ratio of any major building material. Its light weight imposes less of a load on the foundation, which reduces the chance of a home being damaged by foundation settlement. The lower load may also allow structural changes to the transportation system used with HUD-code homes, thereby reducing costs.
- Because steel-framed structures are lighter and have strong connections (screwed rather than nailed), they can better withstand stresses caused by high winds and seismic forces.
- Steel is non-combustible; it does not burn and will not contribute to the spread of a fire, but it will lose structural integrity as temperatures increase in a fire.
- Steel is dimensionally stable; it does not expand or contract in reaction to moisture in the environment; it does not rot, warp, split, crack, or creep; nor is it vulnerable to termites or any type of organism.

Despite these benefits, there are many challenges to the more widespread adoption of steel framing for residential construction. Steel's drawbacks include the following:

- The primary connector used in steel framing is the self-drilling screw. This fastener is labor intensive when compared to framing a wood-frame home with a pneumatic nailing gun. While new fastening systems are available that utilize crimping, welding, and pneumatics to speed up the construction process, the viability of these alternatives have yet to be demonstrated in residential construction.
- The transfer of vertical loads relies on vertical alignment of studs, joists, and rafters because the top track typically is not capable of transferring these loads. This framing technique is called in-line framing. An alternative to in-line framing for vertical load transfer uses heavier framing members, often made of wood, structural steel or built-up light-gauge steel members, in addition to the top or bottom steel track.
- While the framing layout of a steel house is similar to that of a wood house, the assembly skills are significantly different. Carpenters must substantially adjust their movements and practices to use a screw gun rather than a hammer or pneumatic nail gun.
- To fasten steel members requires two steps: clamping the assembly and driving the screw. Overhead connections are particularly difficult, and a step ladder may be required to assemble a steel wall in the air.
- Steel conducts heat and cold at a much higher rate than wood. Low resistance to heat flow is referred to as "thermal bridging": steel studs are an effective medium for heat transport, thereby reducing the overall thermal resistance of the building envelope. Thermal bridging can be mitigated by installing an exterior rigid insulating sheathing that completely covers the steel framing members. However, such insulation can be costly.
- While not vulnerable to rotting or termites, steel is susceptible to corrosion, especially if exposed to salt-laden air in seaside environments.

Presently in the United States, steel is in ample supply and prices are stable. In many areas, steel framing is cost effective compared to wood framing.⁶ However, its cost effectiveness is largely a function of the relative cost of wood and light-gauge steel materials. In fact, the price of steel materials has been consistent since 1980, while the price of wood materials has fluctuated, often dramatically.⁷ At current steel price levels, steel is less expensive than wood on a first-cost basis when the Random Lengths Composite Index for wood framing lumber is \$359 or higher. However, if the builder/framing contractor is new to steel, labor costs could be significantly higher for steel framing—as much as \$1.00 to \$2.50 higher per square foot.⁸

1.3 PREVIOUS RESEARCH

The work to develop a cost-effective light-gauge steel frame solution for factory built homes began in 1998 with an effort to assess the viability of substituting steel for wood as the structural skeleton of homes built under the HUD manufactured home standards. That work culminated in the publication of a design for a steel-framed HUD-code home that was nearly equal to a wood-framed home on a first-cost basis. This design was approved by a Design Approval Primary Inspection Agency (DAPIA), demonstrating acceptance of steel framing under the HUD standards. The results were published by MHRA in March 2002 as *Design for a Cold Formed Steel Framed Manufactured Home: Technical Support Document*. This design, however, was not cost optimized, suggesting that the benefits of steel could be improved by value engineering and design refinements. The major findings of this research included the following:

- Cold-formed steel is a viable structural alternative to wood; it can meet the requirements of the HUD standards.
- On a materials-only cost basis, a steel design, even one that is not cost-optimized, can be competitive with wood for least-stringent design conditions (HUD wind zone I and southern thermal zone).
- Hybrid designs deserve consideration. In some instances, it may be more cost effective to use cold-formed steel in conjunction with wood (such as steel floors and walls with wood trusses).
- Future development of steel designs should include suppliers that might contribute proprietary solutions that are cost-effective and flexible. For example, certain companies have proprietary truss shapes or flooring systems that could prove to be economical solutions.
- The area of fasteners is rapidly evolving and will be one of the major factors that determine the future viability of steel framing in manufactured housing.
- More testing is needed to demonstrate the soundness of using cold-formed steel framing in more economical and structurally efficient ways.
- A design that uses steel studs for virtually a one-to-one replacement of wood studs is not likely to be the most cost-effective solution. The opportunity exists to develop more unconventional and potentially more cost-effective solutions using cold-formed steel in

⁶ See <http://www.toolbase.org/tertiaryT.asp?TrackID=andDocumentID=2037andCategoryID=1024>

⁷ See <http://www.toolbase.org/tertiaryT.asp?TrackID=andDocumentID=2188andCategoryID=1142>

⁸ See <http://www.toolbase.org/tertiaryT.asp?TrackID=andDocumentID=2188andCategoryID=1142>

the future. Such solutions would take advantage of the structural properties and variety of shapes available in steel to develop innovative and highly efficient designs.

The current work takes up the challenge of several of these points, applying the lessons learned in Phase I and building on those results through the application of steel framing in two manufacturing plants.

1.4 STRUCTURE OF THIS REPORT

The research consists of two case studies of the application of steel framing in a factory environment. A case study approach was taken as a way of addressing head-on the major technical issues associated with steel framing in a home manufacturing plant. In each case study, engineers worked with plant staff to develop solutions for a unique combination of market and product-specific conditions.

The first case study focuses on Quality Homes of the Pacific (QHP), a HUD-code home producer that was formed in 2001 in Hawaii. QHP started with the light-gauge steel framing design developed under the Phase I MHRA research. This design, as well as revisions to it, is presented in Chapter 2. Work with QHP was given considerable attention as the company committed to building a new manufacturing facility dedicated to 100 percent steel construction. The technical hurdles faced by QHP and their solutions covered a wide range of issues important to proving the value of steel in the factory environment. Given this unique environment for product development, evolving a viable steel design in partnership with QHP was the major focus of Phase II research.

The second case study documents the engineering of a steel-frame, factory built home design developed in conjunction with R-Anell Housing Group, a producer of HUD-code and modular homes, and commercial modular structures. R-Anell is headquartered in Denver, North Carolina. The company was interested in investigating the feasibility of transferring steel framing technology, which it uses for its commercial modular structures, to its residential HUD-code and/or modular production. This case study is presented in Chapter 3.

Selected elements of the R-Anell modular steel design are included in Chapter 3 with the full set of details contained in Appendix A. Appendix B provides a list of resources including organizations and events that focus on light-gauge steel framing.

2

CASE STUDY:

QUALITY HOMES OF THE PACIFIC

2.1 BACKGROUND

Quality Homes of the Pacific (QHP), located near Honolulu, Hawaii, originated as a producer of manufactured homes. QHP began manufacturing homes under the HUD standards in early 2002 and is the second HUD-code producer to be certified in Hawaii (the first producer ceased operations several years ago). QHP is 50 percent privately owned, with the balance owned by the Office of Hawaiian Affairs and the non-profit Hawaiian Community Development Board (HCDB).

The company operates out of a former aircraft hanger facility (Figure 2-1) about eight miles west of Honolulu and within easy reach of shipping ports used to barge homes to nearby islands. The plant has shipped HUD-code homes to sites on Oahu and Kauai, with a approximately 25 homes shipped since operations began. HCDB has recently placed an order for 50 homes to be delivered over the course of the next six months.



Figure 2-1 The Quality Homes of the Pacific plant

As part of the case study research for this report, MHRA provided technical and logistical support to QHP. QHP started with the designs developed by MHRA's Phase I steel framing research. In 2002 these designs were modified for the Hawaiian market and its HUD-code wind zone III requirements. The company shipped the first all-steel production homes later that year. For reasons discussed below, the company determined that the steel designs were not cost competitive

with alternative methods of construction. In response, QHP shifted from building HUD-code homes to building light-gauge steel-framed modular homes under the Uniform Building Code (UBC) as adopted by the City and County of Honolulu. MHRA continued to work in partnership with QHP during this product transition, playing a supporting role in conducting the re-engineering effort and identifying value improvements to the designs. The changes in manufacturing method and design were largely driven by economic considerations (the main goal of this value engineering was to find a least-cost solution, taking into consideration material, labor, and production costs) and the desire for greater design flexibility. The implications of these changes are discussed later in this chapter. Production volume has been low as the company develops and refines its manufacturing methods and grows sales.

2.2 OBJECTIVES OF THE WORK WITH QHP

QHP's target market is affordable housing for native Hawaiians. High construction costs in Hawaii have placed new housing out of reach to affordable housing buyers, leading to an enormous pent up housing demand. With most materials imported to the Hawaiian Islands, costs far exceed comparable construction on the mainland. Factory built housing holds forth the promise of substantially reducing building costs and putting quality shelter within reach of buyers with modest incomes.

The particular characteristics of the Hawaiian housing market increase the competitiveness of steel as an option for residential construction and result in a more tolerant environment for refining what is fundamentally a new technology for HUD-code homes. These characteristics include:

- Hawaii has a devastating problem with the Formosan termite, which gives an advantage to any building product not made of wood, particularly materials in contact with or near the foundation.
- Almost all building products must be imported from the mainland. Steel is lighter in weight and less bulky than wood framing.
- Land values are quite high and therefore slight increases in the cost of a structure do not have a great impact on overall affordability. However, the state of Hawaii has made land available to native Hawaiians for a nominal fee, creating the opportunity to build affordable housing if construction costs can be reduced.
- Hawaii is in a high wind speed region (HUD wind zone III); therefore, stiffer structures with stronger connections have an advantage.
- The thermal challenges of using steel are a minor factor in Hawaii given the islands' mild climate.

Because of these factors, the Hawaiian site-built residential construction industry has grown accustomed to using steel framing and homebuyers accept steel-framed homes and understand their advantages. In fact, more than 70 percent of all new homes constructed in Hawaii use light-gauge steel for all or part of their structural frame. Despite this, no light-gauge steel framing system for factory built housing had been developed in the islands.

Because the Hawaiian market is quite different from, and not easily comparable to, the mainland housing market, some of the methods used at QHP may be cost-competitive in Hawaii but not on the mainland. However, as described below, QHP provides an ideal "laboratory" for refining the

use of steel framing technologies in a factory environment by addressing many of the product design and manufacturing issues confronting factory builders in other market areas. In the first years of operation, QHP overcame many technical, marketing, and production hurdles to bring its steel-frame product to market. Nevertheless, considerable opportunities remained for value engineering of the homes to improve QHP's position in the Hawaiian market and to provide the basis for exporting the technology to the mainland.

The underlying problem with the original design was that it was not cost-competitive with site building alternatives. As the initial designs evolved, it became clear to the company that it had to make radical changes in its building practices if it was to produce housing within the financial reach of the affordable home buyer. MHRA helped facilitate this value engineering work partly with the expectation of finding more cost-effective solutions that could be transferred to the mainland.

2.3 FIRST-GENERATION DESIGNS

QHP started as a manufacturer of HUD-code homes, partly because one of the founding partners was a HUD-code producer on the mainland and, with a target market of affordable housing buyers, HUD-code represented what it believed would be the least-cost construction method. The company made the decision to build the entire structural frame from light-gauge steel, a decision that required resolving product design, fabrication, crew training, regulatory, and installation issues simultaneously. The early months of operation engendered a steep learning curve and low production rates. Over this period, QHP built approximately 25 HUD-code homes that used steel for the entire structural frame.

2.3.1 Design and manufacturing

The plant uses a horseshoe-shaped production line, as shown in Figure 2-2. Wall panels are fabricated in the center of the plant on horizontal framing tables.



Figure 2-2 The QHP production line

The first-generation design had an all-steel welded chassis (Figure 2-3) with inset tires (Figure 2-4) that allowed a home to ride low to the ground, permitting higher wall heights and steeper roof pitches (8- to 9-foot walls are typical, and the minimum roof slope is 4 in 12). This low-profile floor system can easily accommodate openings for stairs. The mild Hawaiian climate requires only electric resistance space heaters, and QHP uses through-the-wall air conditioning units, eliminating the need for a duct system.



Figure 2-3 Steel chassis being welded on the production line



Figure 2-4 Tires are inset into the chassis

Studs are produced to precise lengths at the QHP plant from coils of steel and are pre-punched for screws and wiring (Figure 2-5). The stud forming equipment produces components for walls, floors and roofs. Some thicker material needed for headers is purchased from outside fabricators. Lightweight, high-strength roof trusses are assembled in the plant from precisely cut parts.



Figure 2-5 Steel studs and other components are produced in the plant

Walls are produced off line and assembled on the floor of the home. Next, the roof trusses are fabricated off line and assembled to form the roof structure (Figure 2-6). The ceiling is sheathed and taped prior to joining it with the home. As can be seen in Figure 2-7 and Figure 2-8, the roof is flipped before being set on the walls. Figure 2-9 and Figure 2-10 show home sections with and without the roof in place.



Figure 2-6 Assembled steel roof trusses



Figure 2-7 Roof assembly



Figure 2-8 Gypsum board applied to the ceiling



Figure 2-9 Home section prior to roof installation



Figure 2-10 Insulation being placed in assembled home section

Cross-bracing was provided for shear protection, which is required under the HUD standards for wind zone III (Figure 2-11). Many screws are required to fasten the cross-bracing (Figure 2-12). A typical header composed of steel angles is also visible in Figure 2-11. Welding was also used in critical stud connection points. Figure 2-13 shows a home in the finishing station, where interior work is completed.



Figure 2-11 Portion of framed home section showing cross-bracing and header



Figure 2-12 Cross-brace connection detail



Figure 2-13 Home sections in the finishing station

Home sections are delivered to the home site using standard manufactured home toppers. Figure 2-14 and Figure 2-15 show two early home sets on the island of Oahu. The attached garage seen in Figure 2-14 was fabricated at the plant as a kit and shipped separately. Like most homes in Hawaii, these houses were built over crawl spaces.



Figure 2-14 Installed home with attached garage



Figure 2-15 Installed home with wrap around porch

2.3.2 Issues encountered

Despite the impressive progress made by QHP in creating a steel production process from the ground up, the plant has experienced several major barriers to proving the technology and to gaining a foothold in the local housing market. Issues include the following:

- **Fasteners.** By far the largest technical and economic issue is the number of fasteners and connections required for assembly of a home, and the associated labor time. The plant manager estimates that more than 20,000 screws were needed to complete each home. Each screw is installed individually by hand with a screw gun. QHP estimates that about 15 percent of the total cost of a home (FOB plant) is attributable to connectors alone. About 50 percent of the total plant costs are labor versus about 12 percent (average) for a plant on the mainland.
- **Labor training.** According to the plant manager, carpenters familiar with wood often have a difficult time with the precision and care required in handling steel. QHP had

more success training plant personnel who had little site building experience than with workers experienced with wood framing.

- **Component delivery.** Producing components such as wall studs in the plant is a distinct advantage, particularly in Hawaii—where most materials are imported and deliveries can be slow. While plant managers would like to produce as many steel components as possible in-house, some of the heavier gauge material needed for headers and beams must be special ordered. Delays in getting these parts or rejection of parts that arrive out of compliance with specifications have the potential to wreak havoc on the production process, particularly as production rates rise.
- **HUD wind zone III requirements.** The local building code requires homes to withstand 105-mile-per-hour (mph) winds (three second gust wind speed). The HUD-code requirement for wind zone III requires even sturdier construction capable of resisting approximately 125-mph wind forces when converted to a three second gust wind speed. This was one of the major driving factors behind QHP’s shift to constructing homes under the Uniform Building Code rather than the HUD standards (see second-generation design discussion below). This shift permitted a number of design modifications, including a reduction in the number of fasteners and the elimination of some dedicated shear walls. The shear walls often limited the number and placement of windows in sidewalls. These changes produced savings in both material and labor costs.

2.3.3 Lessons learned from the first-generation design effort

Despite the progress made with using steel framing, the QHP first-generation effort suggested that considerable changes would be required before it could be proven viable in a factory environment. Despite, or as a result of building to the HUD-code, the first-generation homes built by QHP were far from being cost competitive with site-built wood or steel-framed homes in Hawaii.

The high production costs were, as noted, partly a result of the considerable number of fasteners and the time required for their installation. The number of fasteners alone should not account for the high relative cost since site builders are using similar practices (albeit the company’s goal is to produce homes that are much less expensive than site built). QHP also discovered, however, that the structural requirements for homes produced in Hawaii under the HUD-code exceed the code followed by site builders (Uniform Building Code). Therefore, while perhaps unique to Hawaii, building to the HUD-code became a barrier to producing affordable homes for this market.

In the course of developing their first-generation designs, QHP identified a number of opportunities for improving the factory built, steel-framed homes, including:

- Build the homes to the modular code rather than HUD standards
- Value engineer the structure, taking advantage of the structural properties of steel
- Simplify the connection details, reducing the number of fasteners
- Re-think connection methods so there is less reliance on screw-type mechanical fasteners
- Reduce the number of fasteners generally, particularly in the trusses and siding
- Use a less costly, improved ridge beam design

- Employ a better system for cross-bracing the shear walls
- Develop simpler, more robust methods of squaring the chassis frame for welding
- Improve labor training methods

These opportunities were pursued by QHP with assistance from MHRA starting in early 2003 resulting in the second-generation design.

2.4 SECOND-GENERATION DESIGN

QHP's commitment to steel framing and desire to minimize cost and value engineer the first-generation design continued to represent a living laboratory for evolving a competitive steel-framed solution for factory building. Since this work promised to have direct application for manufacturers operating on the mainland and create an affordable home for Hawaii, MHRA continued to support QHP's efforts, providing engineering and design support.

The entire home design was open for redesign, and much of the structural system was re-engineered. However the focus was on parts of the home that were most in need of value engineering, including most of the light-gauge steel framing members and connections. The engineers did not change the chassis (except for reversing the outer "C" channel and providing the option for hollow structural section [HSS] members) or the roof trusses (except for the connection details at the ridge and eave). Additionally, the engineers only considered the design loads on the installed home and did not consider additional loads imparted on the home during transportation, as QHP had not experienced significant transportation damage in the first-generation designs⁹.

This re-engineering process, conducted in consultation and cooperation with QHP staff, resulted in many design changes intended to yield materials and labor savings, as described below.

2.4.1 Roof

The original design utilized metal roof trusses spaced 16 inches on center. The steel trusses were produced in the factory from a top chord, bottom chord, pony wall, and diagonal brace (Figure 2-16). The homes were shipped with the roof folded down and then assembled on site using the process shown in Figure 2-17. During assembly, the top chords with roof deck are lifted up and the pony wall and diagonal brace are fastened into place. This hinged roof system proved difficult to erect on site and the plant switched to building fully assembled steel trusses (Figure 2-18) in the plant and shipping the homes with the roof pre-finished (Figure 2-19).

⁹ Homes that traveled approximately 70 miles across Oahu over poor roads were inspected and found to have only minor wallboard cracking over windows, and were easily repaired.

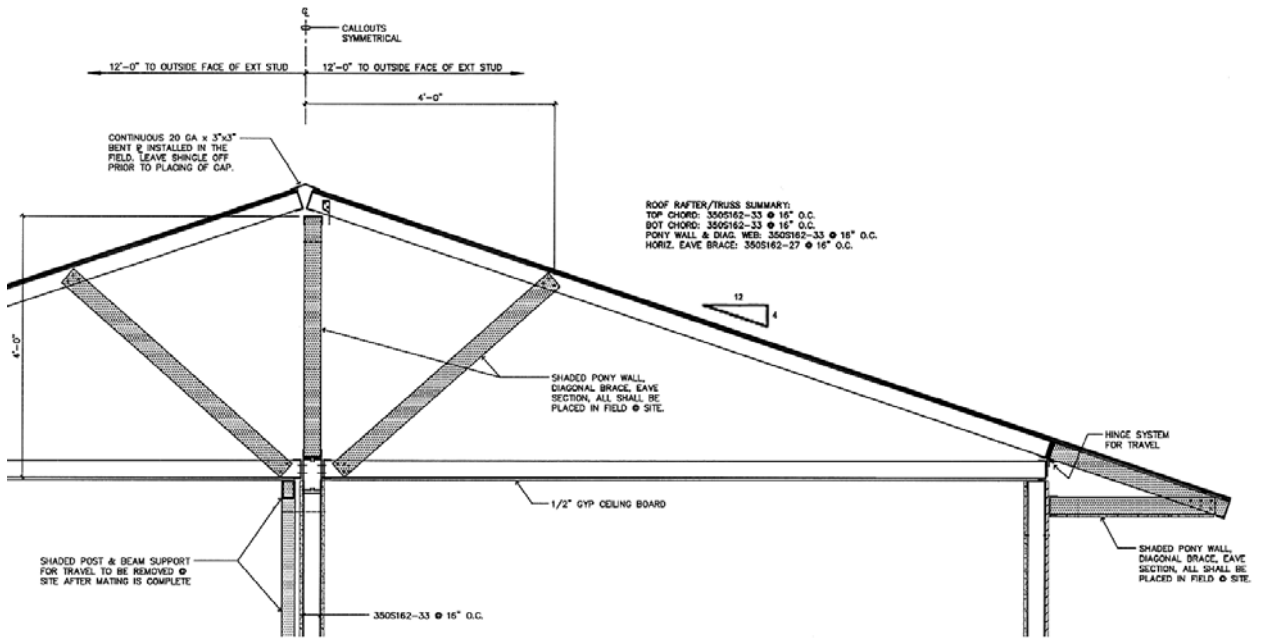


Figure 2-16 Steel roof truss (original design)

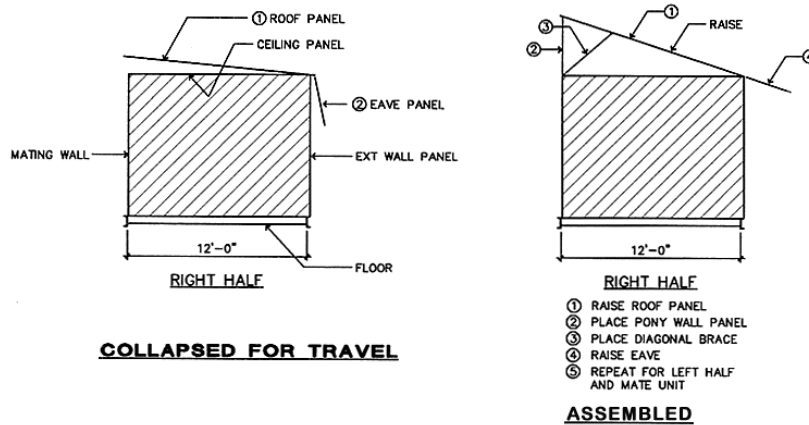


Figure 2-17 Steel roof assembly sequence (original design)



Figure 2-18 Roof trusses being connected to the ceiling board



Figure 2-19 Trusses and assembled home sections

The new design replaces the steel trusses with wood roof trusses. Both wood and steel trusses are competitively priced from a variety of local suppliers and are less costly than the steel trusses produced by QHP in-house. Wood trusses were selected over steel trusses (although an option for steel trusses is retained in the design) because the additional cost of constructing an eave soffit is unnecessary with wood trusses and the exposed rafter ends is a desirable design feature in Hawaii.

The wood trusses are “drag” trusses, meaning they have heavier duty connection plates, enabling them to contribute to the lateral stiffness of the home by distributing the load to all wall segments.

In addition, the trusses can now be placed further apart (24 inches on center), eliminating one-third of the roof trusses, reducing labor and material costs by about 33 percent of the truss system cost.¹⁰ This is possible without any increase in strength of the individual trusses. The original truss spacing (16 inches on center) was necessary to align with the wall studs (Figure 2-20). The use of a structural top track or the increase in the wall stud spacing to 24 inches on center (permitted by the reduction in the design wind speed) allows this increase in truss spacing.

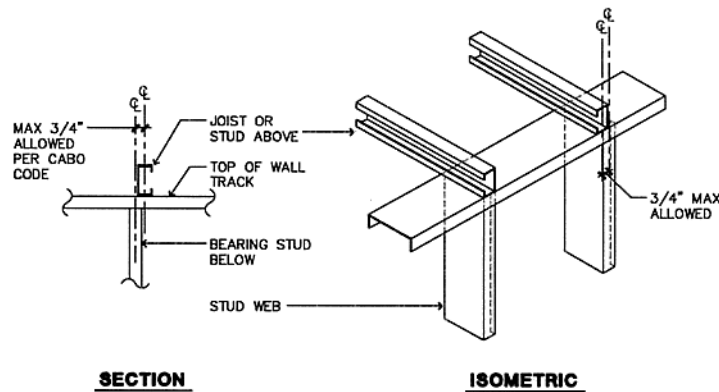


Figure 2-20 Typical truss and joint stud alignment (original design)

¹⁰ All cost figures and comparisons were provided by Quality Homes of the Pacific personnel.

Under the HUD standard requirements for wind zone III (approximately 125-mph three second gust design wind speed); QHP built only straight gable roofs because it was an easier architectural solution to meet the structural requirements. Under the UBC wind speed requirements, it is simpler for the plant to build Dutch hip and hip roofs in addition to straight gables, which increases home acceptability in the marketplace.

2.4.2 Walls

The original exterior wall design utilized 5/16-inch fiber-cement siding over 3½-inch, 20-gauge steel studs spaced 16 inches on center. The new design utilizes 3½-inch, 18-gauge steel studs. 18-gauge studs and track yield higher screw connection strengths, permitting a reduction in the number of screws and associated reductions in labor costs, although it does reduce the throughput on the stud fabrication equipment by 10 to 15 percent.

The new design also offers QHP the option of using 16-inch on center stud spacing with one of two structural top plate designs (see Section 2.4.3 and Figure 2-25 and Figure 2-26), or spacing the studs at 24 inches on center to maintain alignment with the trusses and eliminating the structural top plate. Without aligning studs and trusses, a structural top plate is required as the light-gauge steel top track is not able to distribute vertical roof truss loads laterally to the studs. Moving to studs spaced 24 inches on center reduces the material and labor costs for the wall stud system by approximately 20 to 25 percent.

Aligning the studs and trusses is sometimes a challenge: it requires greater assembly precision in the plant and may increase labor time. Using a structural top plate with studs spaced 16 inches on center increases costs (approximately \$400 in materials and labor for the top plate) but provides additional design flexibility and structural redundancy. It also enables a homeowner to retrofit windows and doors with greater ease because studs can be relocated without the need to place them directly under roof truss locations. Additionally, planned testing may provide evidence that inclusion of a structural top plate permits the elimination of headers over small (3-to-4 foot wide) windows and doors, although this would have to be accepted by the building code agency before it could be specified for use in the new design.

Moving to 24-inch on center stud spacing poses no problem; however, the fiber-cement board has not been rated by the siding manufacturer for a 24-inch span at the 105-mph design wind speed. The other option under consideration is switching to an exterior-grade plywood siding product, which has the drawback of requiring priming as well as painting. Fiber-cement siding is preferred due to its low maintenance, termite resistance, and need for only a finish coat of paint (it is pre-primed). Finally, regardless of the type of siding material, the walls with studs spaced at 24 inches on center feel less solid, which is a marketing drawback.

QHP plans to experiment with both options and determine which design is preferable from a cost and marketing standpoint. In both the old and new designs, the interior walls utilize 3½-inch, 20-gauge studs at 24 inches on center with gypsum board on both sides.

2.4.3 Eave overhang

Homes in Hawaii typically have large eave overhangs to shield them from the strong tropical sun. To facilitate transport of a house over narrow roadways, the eaves in the original design were hinged to the end of the roof truss (Figure 2-21). On site, the eave was flipped up and the soffit panel was inserted to hold it in place (Figure 2-17). This system never worked properly in the field and was modified by plant personnel to eliminate the hinge shortly after production commenced. The bulk of the plant's production employed a fixed eave that was an extension of the steel truss top chord (Figure 2-22).

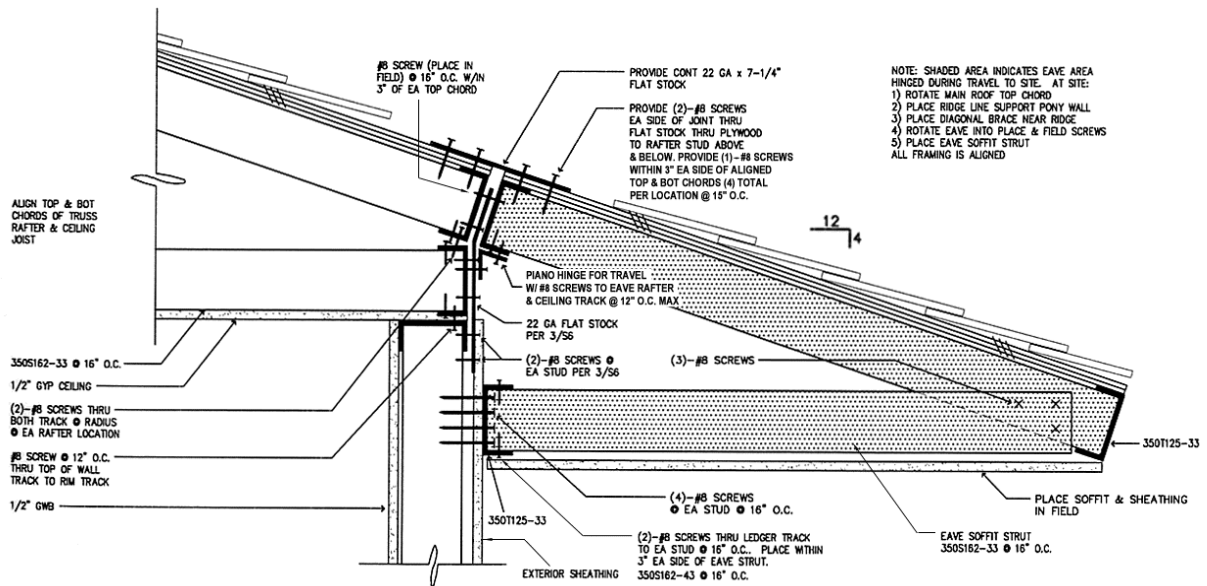


Figure 2-21 Truss rafter and ceiling panels (original design)



Figure 2-22 The eave overhang with soffit vent



Figure 2-23 Connection of the truss to the wall studs

A cap channel runs along the eave and is fastened to the bottom chord of the truss and the wall stud with a steel strap (Figure 2-23). This detail provides a simple and strong tie-down connection. The new design will offer this detail as an option in the event that steel trusses are used. Because the primary version of the new design uses wood trusses, however, the eave detail has been modified as shown in Figure 2-24 through Figure 2-27. In the new design, the eave is also shipped fully assembled.

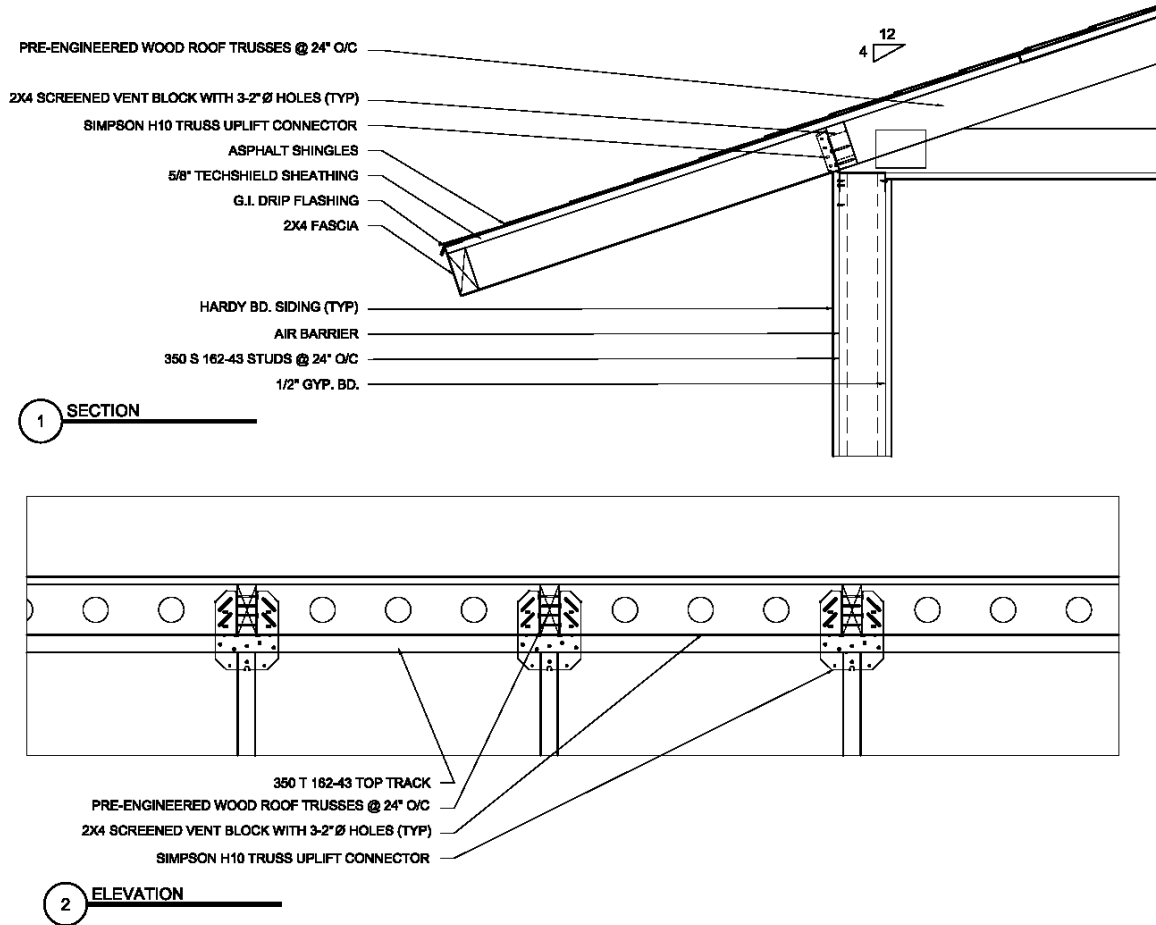


Figure 2-24 Eave detail with non-structural top track (revised design)

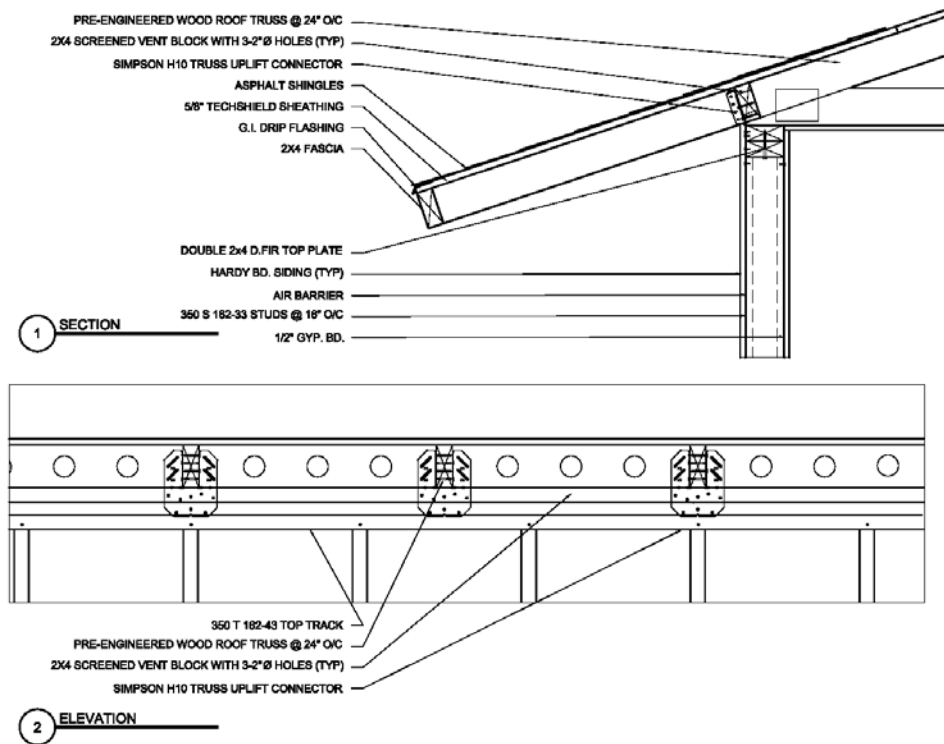


Figure 2-25 Eave detail with structural wood top plate (revised design)

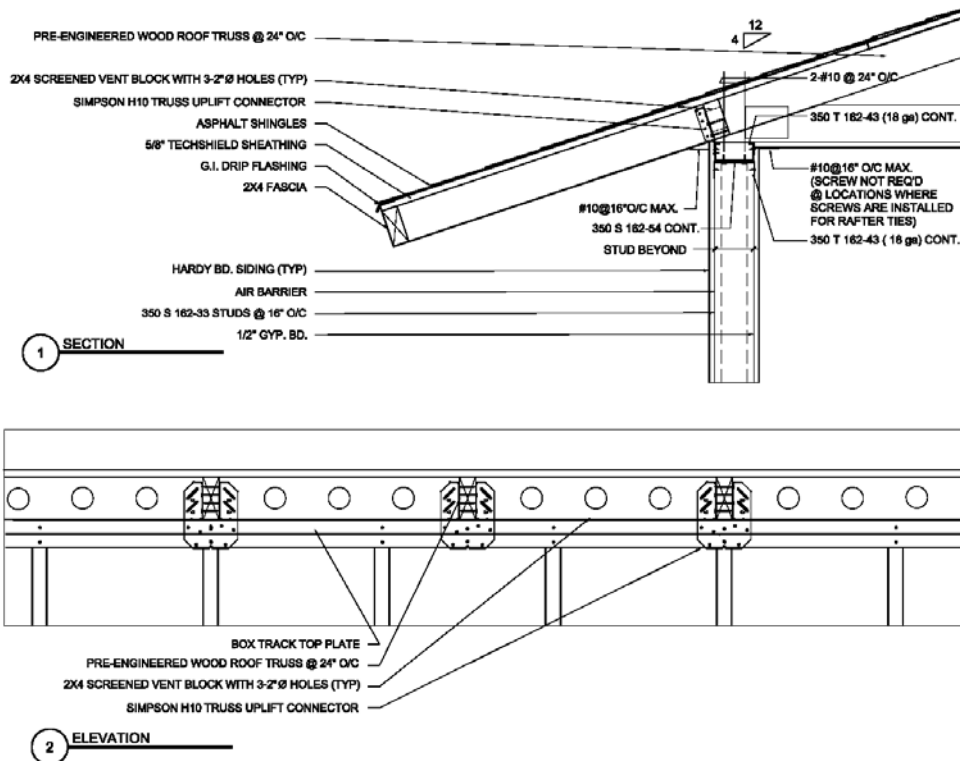


Figure 2-26 Eave detail with structural light-gauge steel box track (revised design)

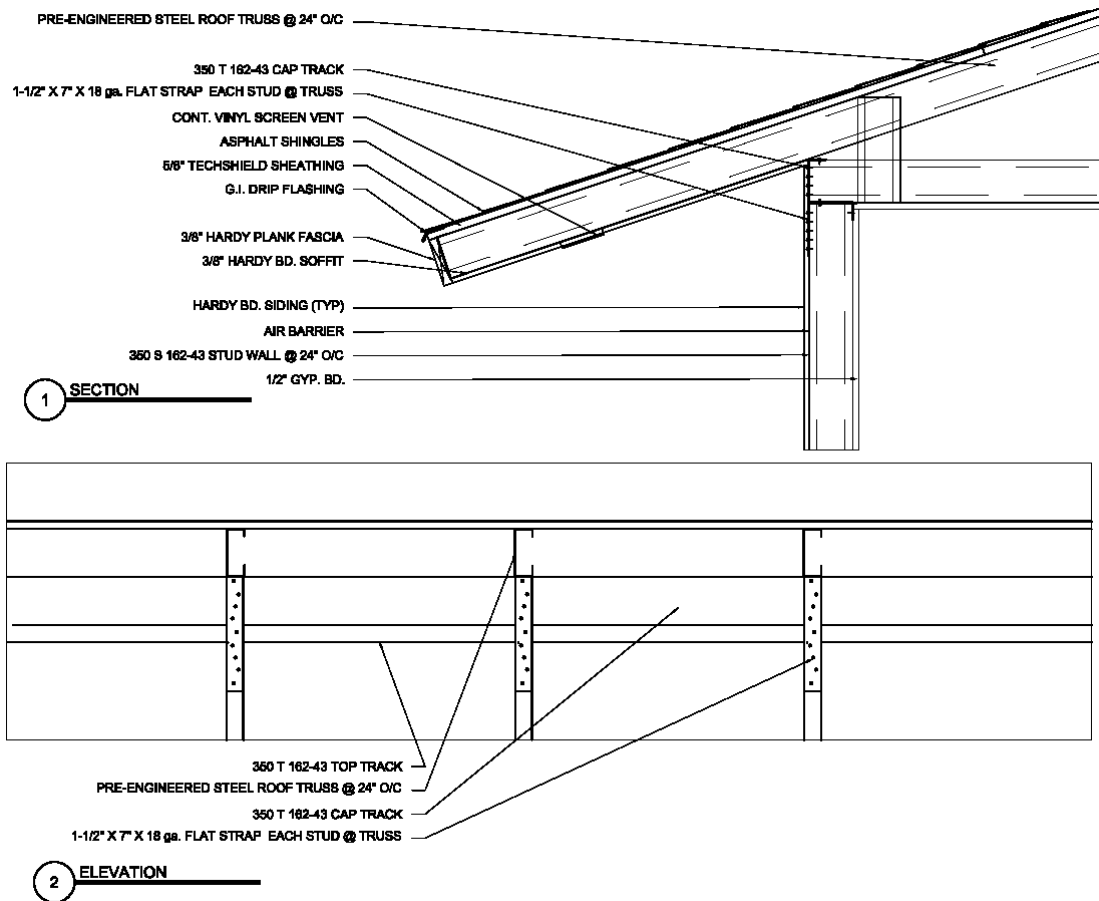


Figure 2-27 Eave detail with non-structural track and metal roof truss (revised design)

The increased width of the home due to the fixed eave has not posed a problem for transportation.

2.4.4 Ridge beam

In the original design, a box ridge beam (Figure 2-28 and Figure 2-29) was pre-attached to the bottom chord of the truss on half of the home and connected to the second half in the field after the roofs were lifted up and the halves of the home joined together. This system required making difficult field connections from inside the attic crawl space at each truss location along the ridge line (Figure 2-30) and along the box ridge beam. The new design calls for installing a split girder truss on each half of the house, permitting a simpler connection detail (Figure 2-31). The two trusses are fastened together at convenient locations, substantially reducing field assembly time.

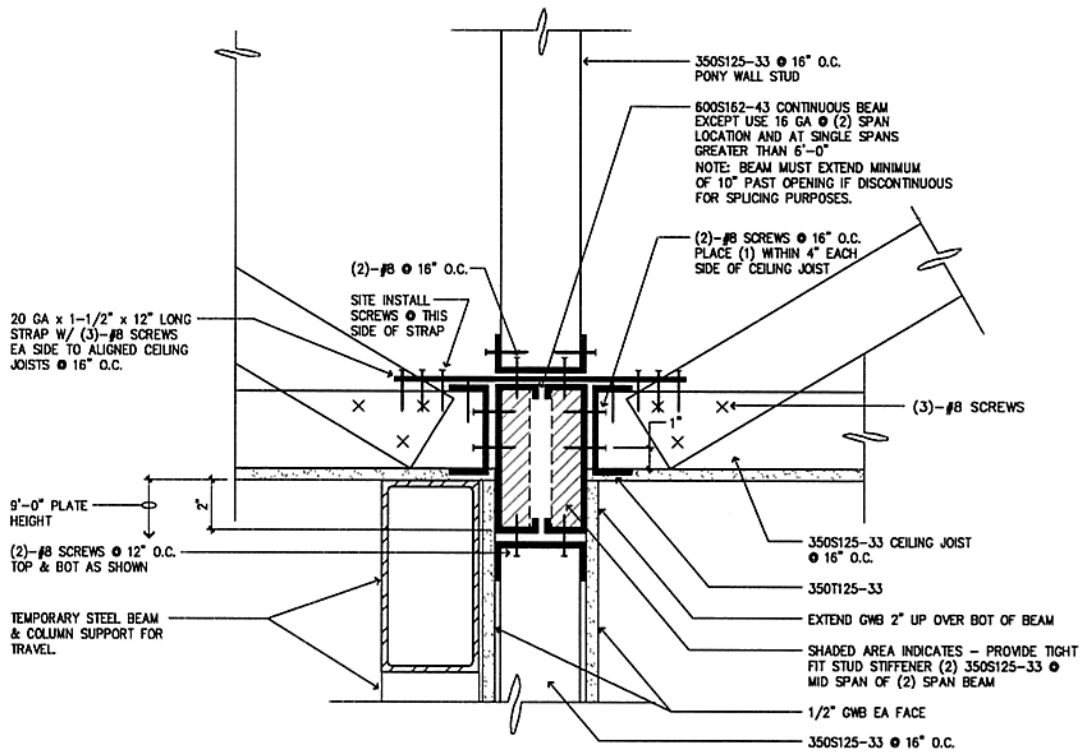


Figure 2-28 Ridge line pony wall and continuous beam (original design)

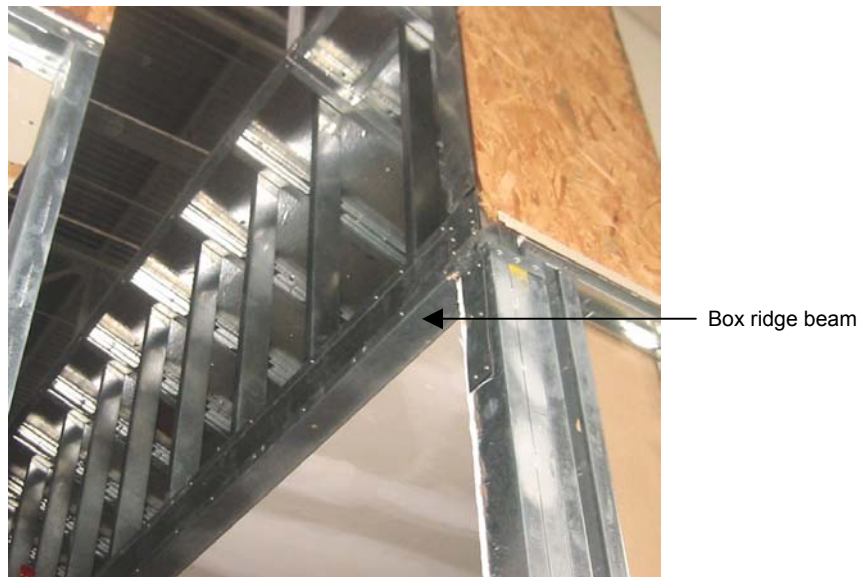


Figure 2-29 View into the roof cavity showing the box ridge beam

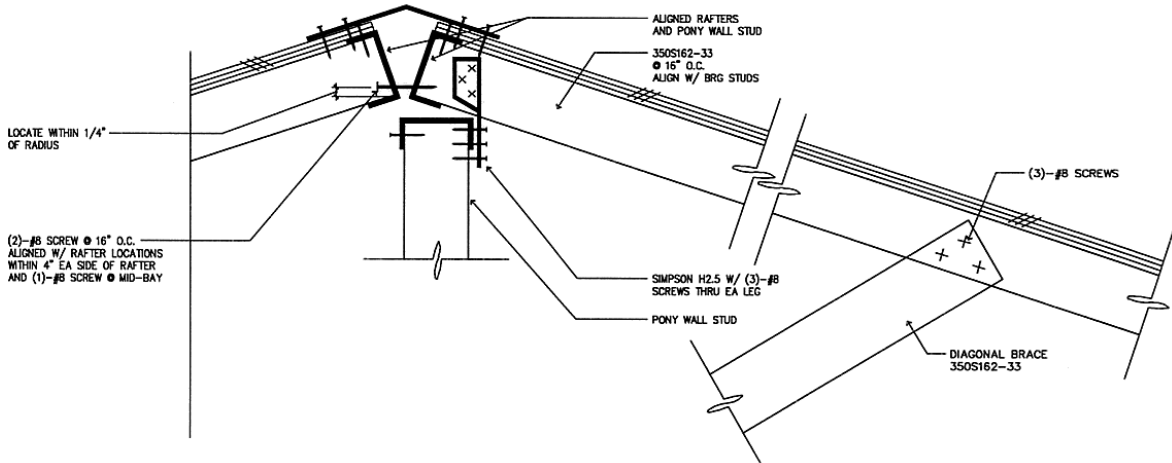


Figure 2-30 Ridge (original design)

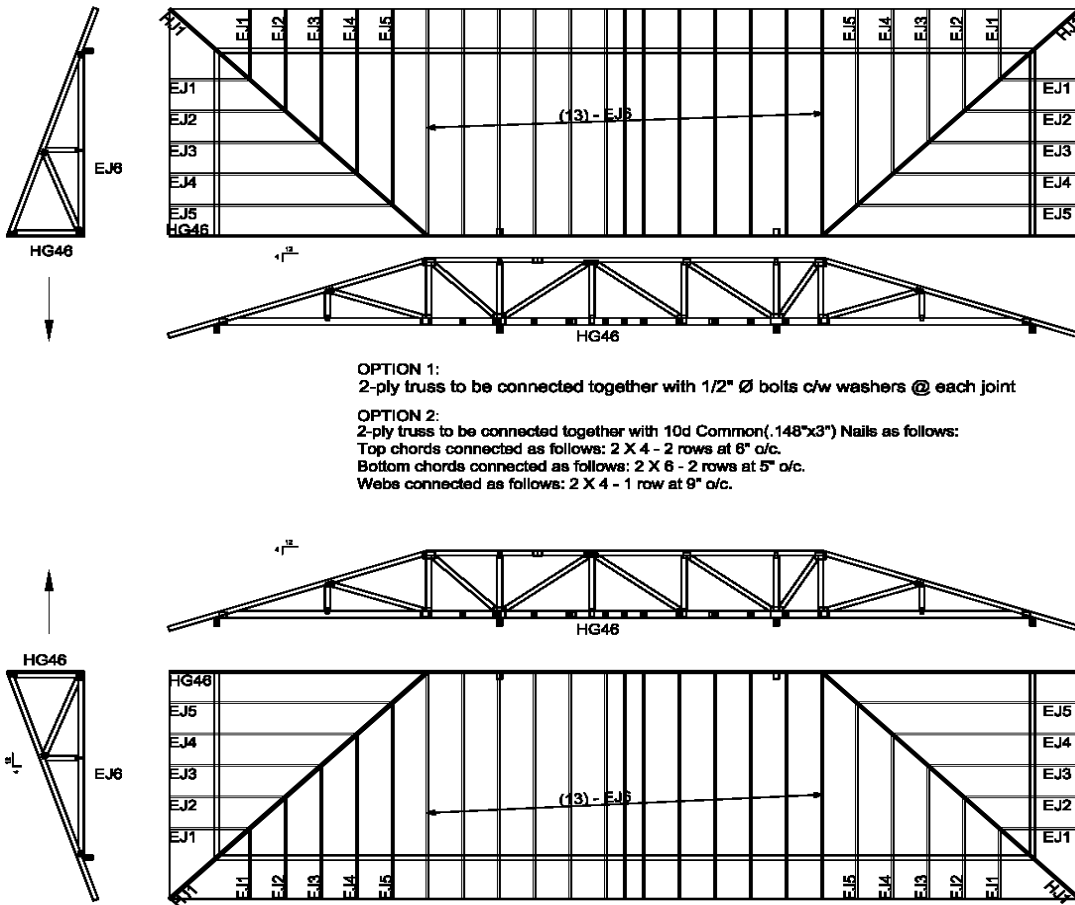


Figure 2-31 Split girder truss ridge beam (revised design)

2.4.5 Shear wall design

Lateral stiffness was imparted to the home in the original design by steel cross-braces built into 8-foot wall sections (Figure 2-32 and Figure 2-33).¹¹ This design did not take advantage of the contribution of the exterior and interior walls to the lateral stiffness of the home. At each leg of the cross-brace was a 9-inch wide strap connected to the framing with twenty-eight #10 screws (Figure 2-34). Not only were these fasteners extremely labor intensive to install, but the numerous screw heads caused the exterior sheathing to bulge over them, compromising the esthetics of the home. The switch to the UBC code and its resulting decrease in design wind speed¹² reduced the structural requirements on these braces (which were over-designed, even for the 125-mph three second gust design wind speed). This switch permitted a reduction in the number of screws per connection—a reduction of approximately 100 screws per house (Figure 2-35).

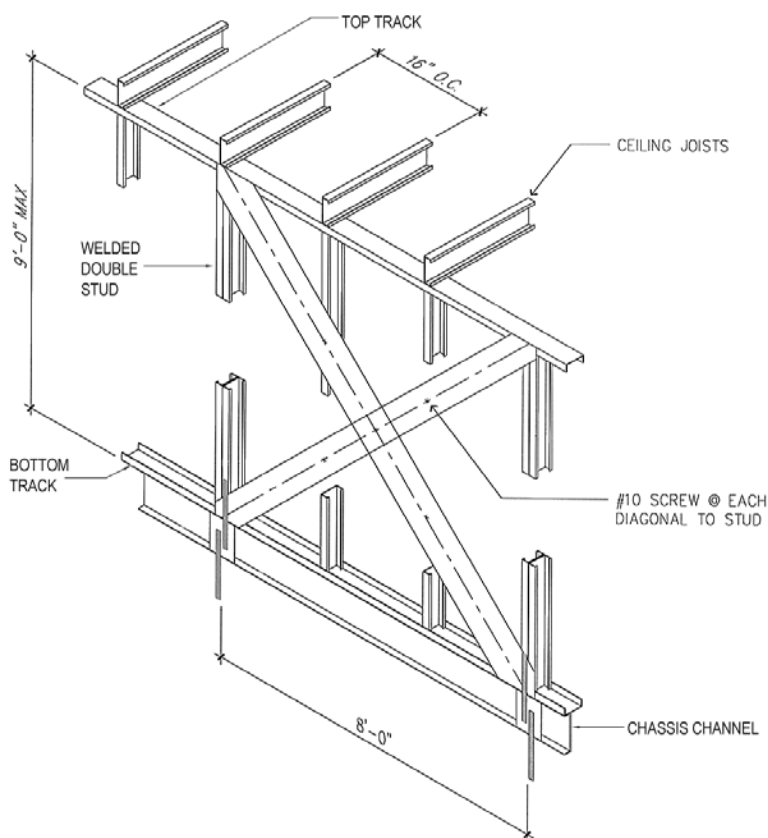


Figure 2-32 Typical X-brace isometric (original design)

¹¹ During transportation of the houses, the longer models (i.e., 44-foot and 52-foot) had showed some minor cracking in drywall due to flexing of the cantilever portion of the chassis. (The section between the axle and truck frame performed satisfactorily.) Several ideas, such as adding an interior cross-brace shear wall, were tried to stiffen the system, without success.

¹² With regard to shear wall design, UBC is less restrictive than the HUD standards in that it allows the interior and exterior walls, and the roof/ceiling diaphragm, to be calculated as contributing to the lateral strength of the home.

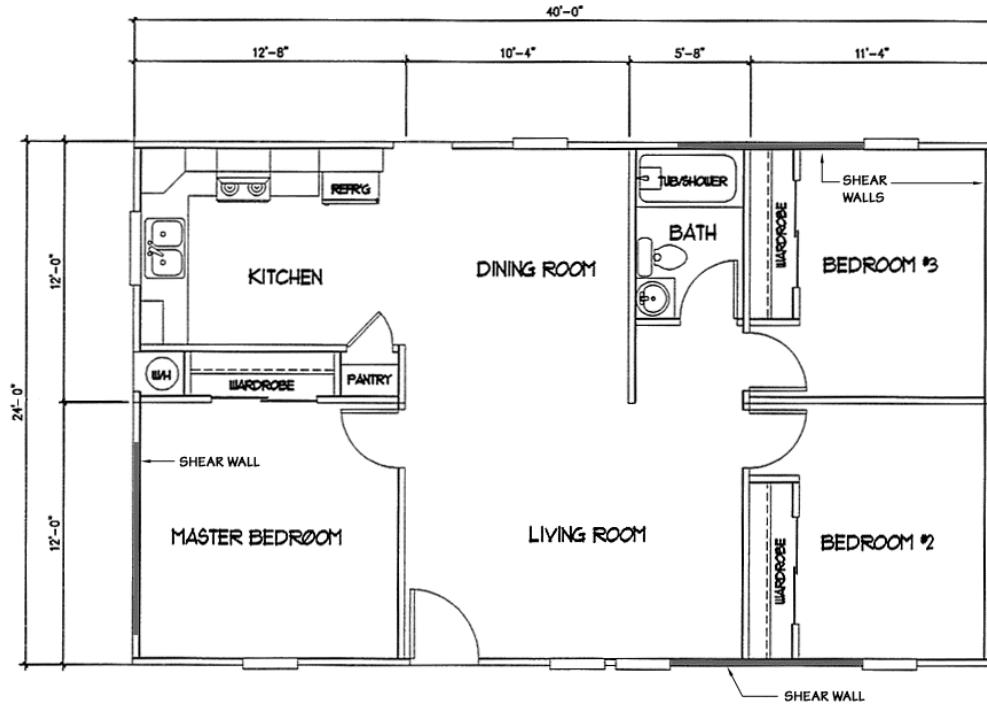


Figure 2-33 Floor plan showing shear walls (original design)

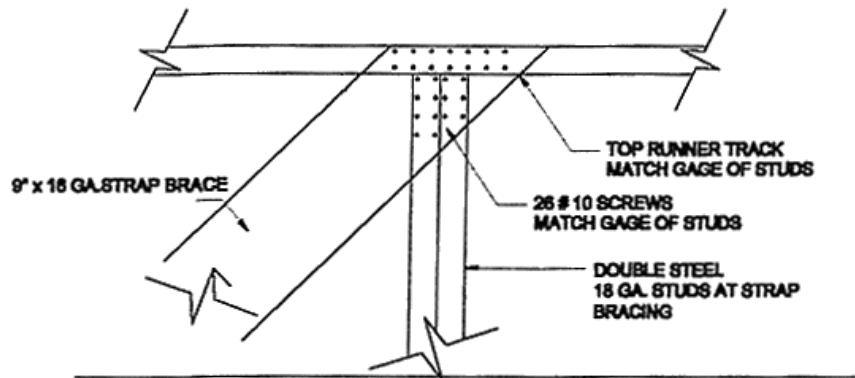
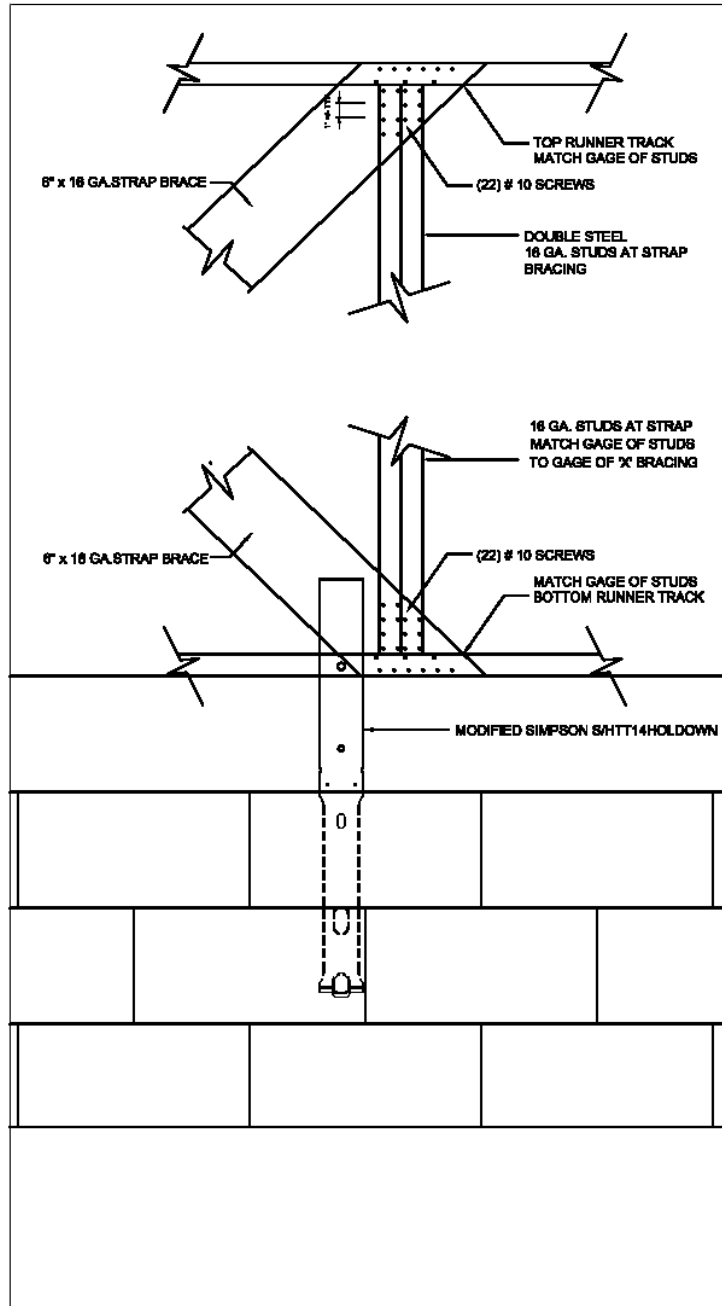


Figure 2-34 Typical X-brace top (original design)



1 'X' BRACE DETAIL ELEVATION

Figure 2-35 Cross-bracing with reduced number of screws (revised design)

QHP is also considering the possibility of eliminating the plant-fabricated cross-braces completely and utilizing a proprietary product called Hardy Frame. Hardy Frame is a pre-manufactured 4-foot section of wall that can be bolted to the top and bottom tracks to provide shear strength (Figure 2-36). One Hardy Frame would be used per side of a finished home. The narrower Hardy Frames provide greater design flexibility and allow larger windows and door areas. However, using Hardy Frame is a more expensive option than the cross-brace system, and so a decision was made to only use them when additional design flexibility is critical.

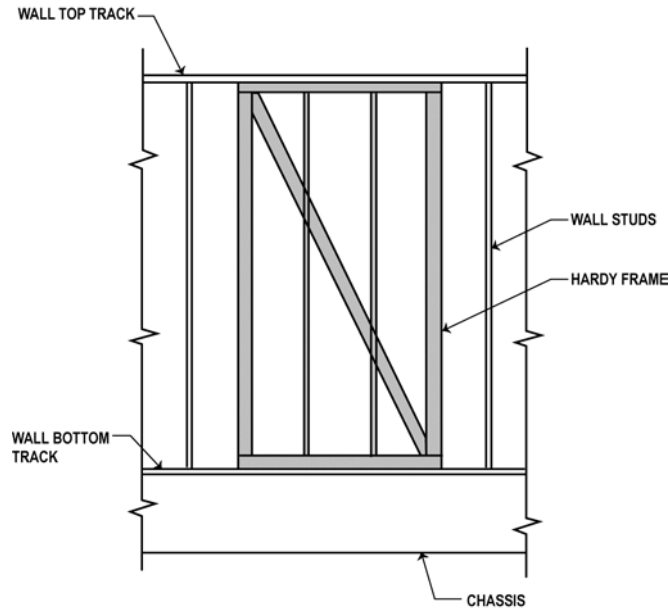


Figure 2-36 Hardy Frame wall track

2.4.6 Floor joists

The light-gauge steel floor joists in the original design were spaced at 16 inches on center for both the 24-foot-wide homes (12-foot joist span) and the 28-foot-wide homes (14-foot joist span). From an engineering standpoint, spacing the joists at 24 inches on center is technically possible, but in the judgment of QHP, the resulting floor tends to flex and feel soft. The plant therefore elected to maintain 16-inch on center spacing. As discussed below, the plant will consider converting to the Dietrich floor system.

2.4.7 Chassis and floor system

The new design continues to use an all-steel welded chassis with inset tires. This allows the home to ride low to the ground, permitting higher walls and steeper roof pitches (8- to 9-foot walls are typical and the minimum roof slope is 4 in 12). This low-profile floor system can easily accommodate openings for stairs.

However, the chassis design was significantly changed. Originally, the C8 x 11½ “C” channels at the perimeter of the chassis were oriented with the open side of the C facing outward and the floor joists welded to the flat, back side of the C (Figure 2-37).

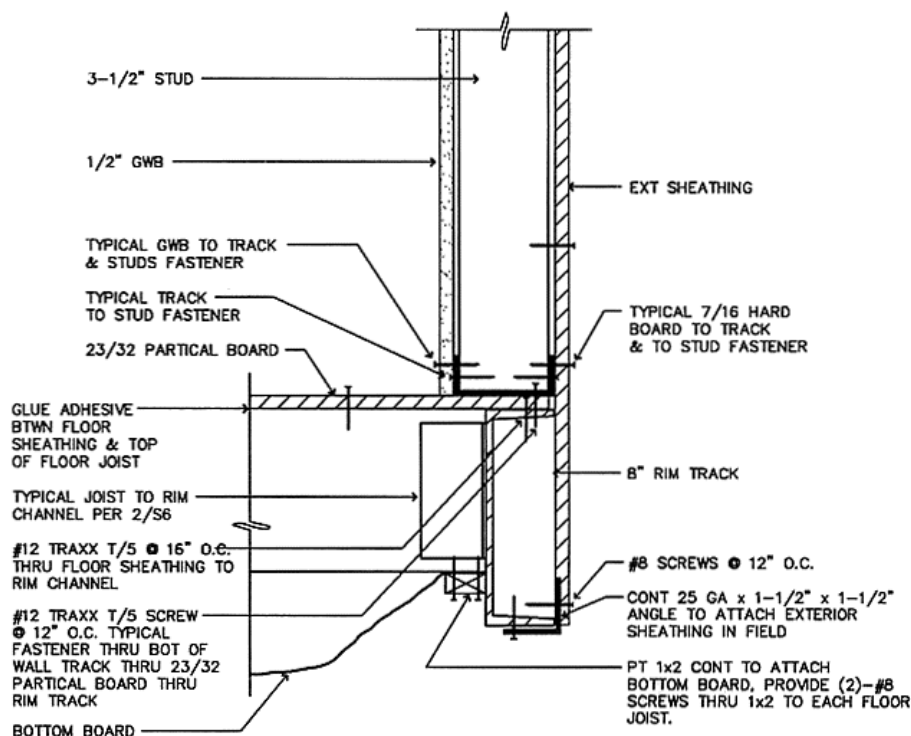


Figure 2-37 Exterior wall-to-floor joist connection (original design)

A continuous “L” angle was fastened to the bottom of the channel to provide an attachment point for the bottom of the siding. The new design calls for the channels to be reversed such that the open portion of the C faces inward instead of outward (Figure 2-38). While this change provides a cleaner exterior finish, eliminating the L angle, it also complicates the joist-to-chassis connection. The back of the C channel provided a large flat surface for welding. The inside of the C channel does not provide enough space for the 16-gauge, 6-inch deep joists, so the joists must be chamfered to slide into the C and then welded to the inside of the channel.

To simplify this connection detail and to reduce the amount of welding, the plant is considering switching from the C channels to HSS tubes (Figure 2-39) in combination with a Dietrich floor system.¹³ The HSS members are slightly heavier (and therefore more costly than the C channels.¹⁴ However, their flat surfaces would offer an ideal location to mount the Dietrich rim track, which comes prefabricated with tabs to accept the 18-gauge, 7¼-inch deep Dietrich joists. A side benefit of the heavier HSS members is that they are approximately 50 percent stiffer than the existing C channel, which may reduce the incidence of drywall cracking in the cantilever portion of the chassis. The additional material costs associated with the heavier chassis will be weighed against the decrease in plant fabrication time and the improvement in chassis stiffness.

¹³ Dietrich is a proprietary floor system. The Dietrich Company provides pre-engineered and pre-cut light-gauge steel components from plant locations in most major U.S. markets, including Hawaii.

¹⁴ The C channel weighs 11-1/2 pounds per linear foot. QHP would use either a 3/16-inch thick 3 x 8 HSS weighing 13-1/4 pounds per linear foot, or a 3/16-inch thick 4 x 8 HSS weighing 14-1/2 pounds per foot.

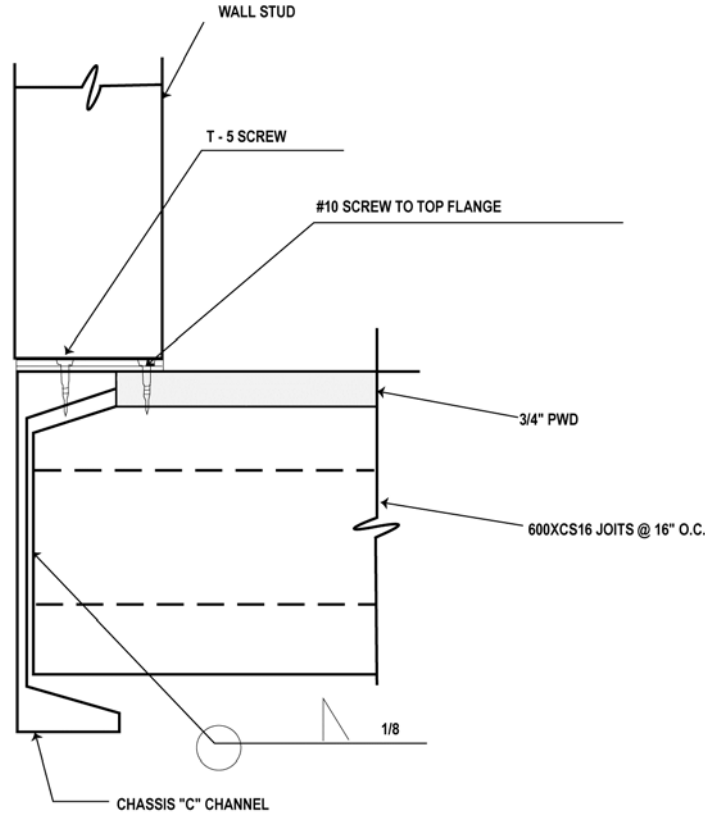


Figure 2-38 C channel floor detail (revised design)

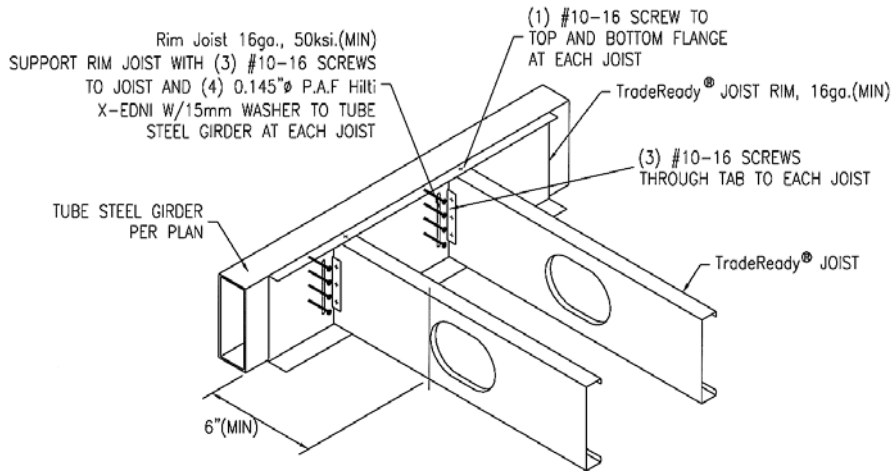


Figure 2-39 HSS chassis beam with Dietrich floor system (revised design)

Another part of the connection detail revision involved relocation of the wood floor decking to make it flush with the top of the C channel. This allows the wall bottom track to rest directly on top of the C channel (Figure 2-40 and Figure 2-41). This metal-to-metal connection is superior to the previous design, which sandwiched the plywood floor decking between the wall bottom track



Figure 2-40 Top of floor decking in same plane as top of chassis channel



Figure 2-41 Detail of wall framing at chassis edge

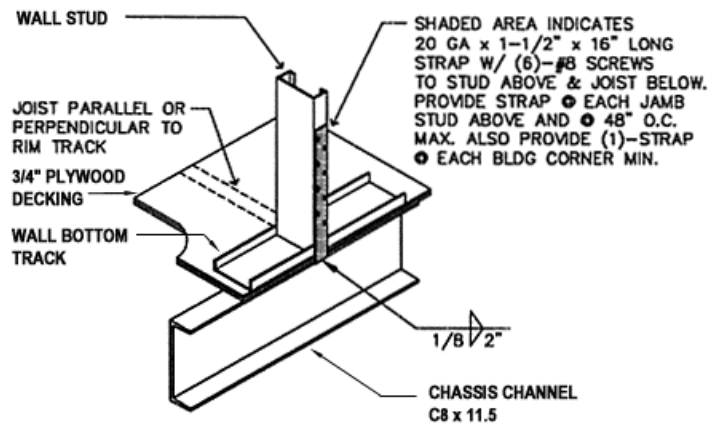


Figure 2-42 Typical wall-to-floor strap (original design)

and the C channel (Figure 2-42). The new connection is stronger and easier to attach with screws.

2.4.8 Foundation system

Like most homes in Hawaii, QHP’s homes are typically installed over crawl spaces. The original design anticipated home placement on relatively costly poured concrete foundation walls (Figure 2-43). After experimenting with several proprietary foundation systems, QHP settled on a foundation using discontinuous concrete masonry unit (CMU) walls.

Lateral strength is provided by grouted and reinforced short CMU walls, which is less costly than the alternatives, and more resistant to corrosion than the exposed metal components of some proprietary foundation products.

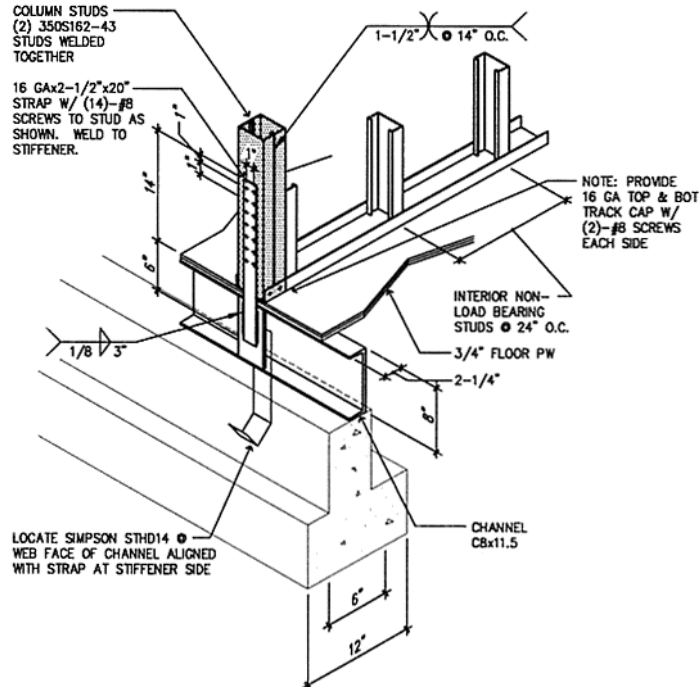


Figure 2-43 Isometric view of interior (original design)

The connection from the chassis to the foundation was also modified to eliminate the need for on-site welding that requires special skills, permits, and the cumbersome installation and relocation of shielding to protect the homes combustible bottom board. Instead of welding the chassis to a steel plate cast into the concrete foundation (Figure 2-44), the new design uses a modified standard metal strap connection (Figure 2-45). This greatly increases the flexibility of home placement and takes 75 percent less time to install than the original welded connections.

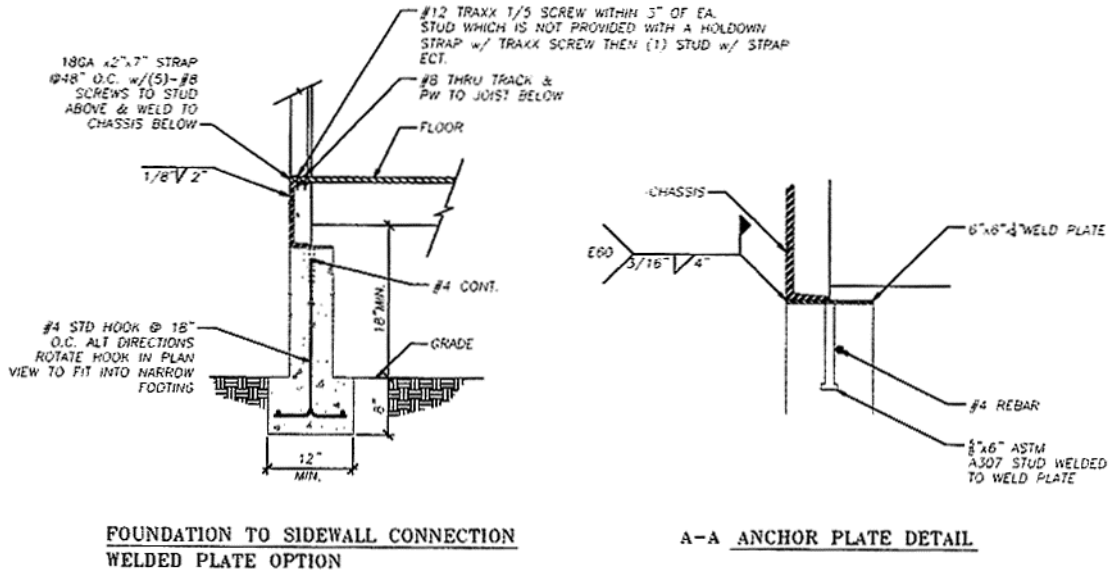


Figure 2-44 Foundation to sidewall connection (original design)

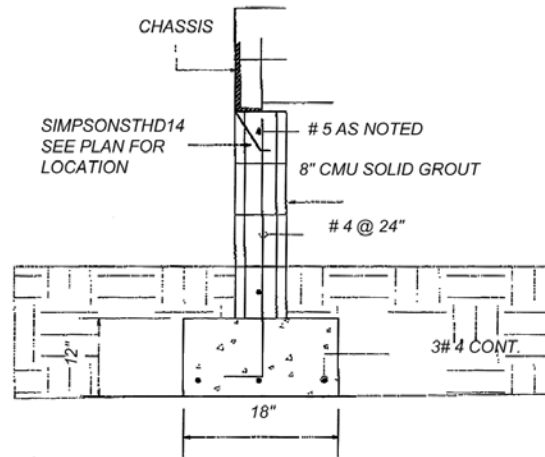


Figure 2-45 Wall anchor plate detail (revised design)

2.4.9 Fasteners

As mentioned above, one of the major issues with the first generation QHP steel design was the large amount of labor that went into fastening the frame together. Additionally, the large variety of screws (up to seven screw sizes, as seen in Figure 2-46) caused confusion in the plant. Workers carry all of these screw types and must select the one—or several types—specified for each connection.

The new design decreased the overall number of screws in the home (partially due to reduced requirements of the UBC code) by reducing the number of screws in many connections, replacing screws with pins (which are much simpler to install) in some connections, and eliminating some connections altogether.

Multiple screw types are still required; however, since connections between varying materials such as cold-formed steel framing members, red-iron chassis members, and fiber cement or plywood siding, have diverse structural and long-term performance requirements.

The pin connections are used as an alternative to T-5 screws for connections between light-gauge members and the chassis. The company is not prepared to specify pins for light-gauge to light-gauge connections until their reliability has been more thoroughly demonstrated.



Figure 2-46 Seven different screw types used in the plant

Not only does the HUD standard translate into requirements for screws that exceed the UBC structural requirements, but it also requires a substantial amount of welding that the plant was able to eliminate with the switch to the UBC. The solution developed and approved under the HUD standard dictated support of boundary elements, such as headers, with welded double studs that had to be strap-welded to the chassis (Figure 2-47 and Figure 2-48). The UBC code permits screwing the double studs together and connecting them to the chassis with straps screwed to both the studs and the chassis (Figure 2-48).

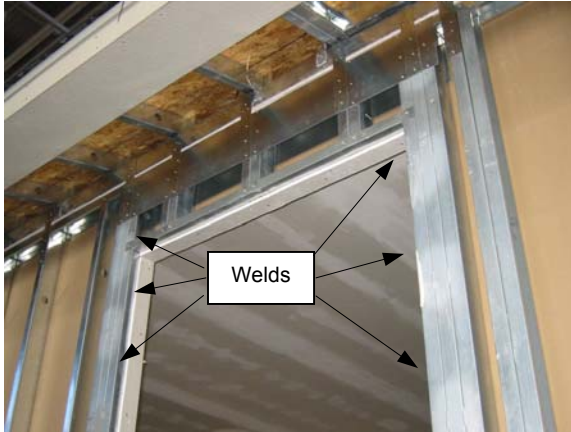


Figure 2-47 Framing at window showing welds, header, and stud-truss alignment

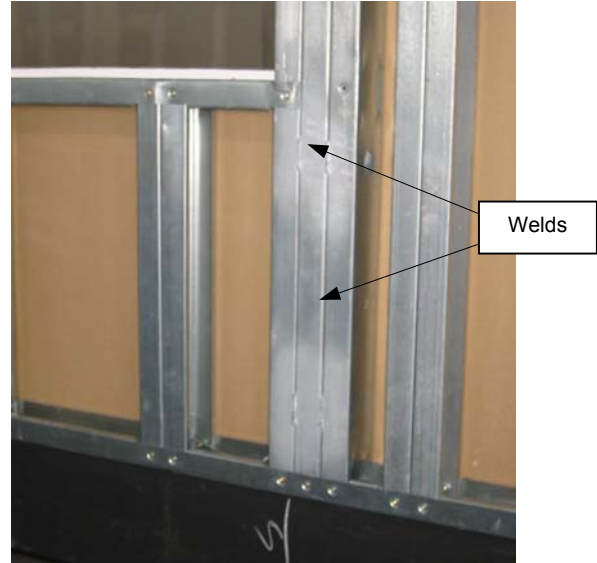


Figure 2-48 Welded studs at window opening

In the future, QHP hopes to further reduce the amount of welding and quantity of screws and convert more connections to pins or other alternative connection types such as rivets.

2.4.10 Corrosion protection

Recent research conducted by the National Steel Framing Alliance and the University of Hawaii has concluded that there is a significant risk of corrosion of steel-framed structures exposed to extreme coastal conditions. The research suggests protecting all exposed steel framing members and connections with an air/vapor barrier. The new QHP design will make every effort to comply with this recommendation.

2.5 SUMMARY OF SECOND-GENERATION DESIGN CHANGES

The re-engineering effort considerably improved the QHP design, reducing the cost of materials and labor, speeding fabrication time, and adding design flexibility. As the company moves through prototyping, the benefits of these changes will be quantified. Table 2-1 below provides a summary of the changes between the two design generations.

Table 2-1. Summary of QHP design changes

Component	First Generation Design (HUD code)	Second Generation Design (modular built to UBC)
Roof truss spacing	16 inches on center	24 inches on center
Roof truss type	Steel	Wood “drag” trusses, option for steel
Roof design*	Gable only	Choice of gable, Dutch hip, and hip
Truss/stud alignment	Aligned	Option for aligned or not aligned
Exterior siding	5/16-inch fiber cement	5/16-inch fiber cement if wall studs 16 inches on center, or exterior grade plywood if wall studs 24 inches on center
Wall stud spacing	16 inches on center	Option for 16-inch or 24-inch on center spacing
Wall top track	Non-structural	Option for one of two structural top tracks if wall studs 16 inches on center; none if wall studs 24 inches on center
Stud size	Exterior walls: 3½-inch, 20-gauge Interior: 3½-inch, 20-gauge	Exterior: 3½-inch, 18-gauge Interior: 3½-inch, 20-gauge
Eave overhang	Hinged design	Fixed eave
Ridge beam	Box beam one side of house	Split girder truss on each half of house
Foundation	Poured concrete foundation system	CMU discontinuous wall
Chassis connection	Chassis welded to steel plate cast-in-concrete foundation	Modified mechanical strap connection detail
Wall bottom track to chassis connection	Fastened to chassis through floor decking	Fastened directly to chassis
Shear walls¹⁵	Factory fabricated “X” braces, 96 inches long	Modified factory fabricated “X” braces (96 inches long) or Hardy frame (48 inches long)
Elements contributing to lateral strength*	“X” braced walls designed to withstand all lateral forces (HUD standards)	Contribution to lateral resistance provided by all walls and the roof (UBC)
Fasteners	Seven screw types, more than 20,000 screws, substantial amount of welding	Seven screw types, fewer screws, reduced welding, more pin connections
Boundary elements	Welded double studs and strap welds to the chassis (HUD standards)	Screw connections (UBC)
Floor joists	16-gauge, 6-inch joists, 16 inches on center	16-gauge, 6-inch joists, 16 inches on center; may convert to Dietrich system

* These changes are the result of building under the UBC as adopted by the City and County of Honolulu, rather than the HUD standards. Among these benefits are the less stringent wind design requirements (reduction to a 105-mph design wind speed from 125-mph) and the cost of the HUD inspection process.

¹⁵ During transportation of the houses, the longer models (i.e., 44-foot and 52-foot) showed some minor cracking in drywall due to flexing of the cantilever portion of the chassis. (The section between the axle and truck frame seemed to perform satisfactorily.) Several ideas, such as adding an interior “X” brace shear wall, were tried to stiffen the system. These were not successful.

2.6 SUGGESTED NEXT STEPS

MHRA provided technical assistance to the QHP plant to assist in refining steel frame design. This research began the process of optimizing the QHP system and identifies areas where further research is necessary. It will be up to the company to continue this process to the point of developing a highly competitive steel frame product.

Future efforts may address the following technical issues:

- Fastening options such as pins and clinching as an alternative to screws, as well as reducing the overall number of fasteners.
- Testing of certain components, such as fiber-cement siding on exterior walls with studs spaced 24 inches on center with 105-mph design wind speeds.
- Determination of what steel components are most efficient to produce in-house at the plant versus out-sourced to fabricators.
- Development of a more efficient system for installing the homes to the foundation.

Important cost, manufacturing, systems integration, and marketing issues must also be addressed:

- In-depth cost analysis for both materials and labor for production by QHP.
- Process engineering analysis to cost optimize the production process and quality control systems.
- Effective methods for training plant staff in the use of steel.

3

CASE STUDY: R-ANELL HOUSING GROUP, LLC

R-Anell Housing Group is a producer of both modular and HUD-code homes. The company is headquartered in Denver, North Carolina. It has two manufacturing facilities: one in Denver, NC and the other in Cherryville, NC. The Denver plant uses wood framing systems to produce both modular homes that conform to the International Residential Code and HUD-code homes built to the preemptive HUD manufactured home standards. R-Anell distributes its homes through builders (modular) and retailers (manufactured) with most homes sold throughout the southeastern and Middle Atlantic states.

The Cherryville operation, formerly one of the largest home manufacturing facilities in the nation, was recently refitted to produce steel-frame commercial structures. These structures are of single-story modular construction using light-gauge components. Entering the market for steel construction required retooling the plant, developing steel fabrication skills, and training plant crews in the handling of steel products. With the combination of steel manufacturing expertise and the existing network of sales centers, R-Anell is well positioned to launch a line of light-gauge steel homes.

3.1 OBJECTIVES OF THE WORK WITH R-ANELL

In contrast to QHP, R-Anell is in the formative stages of evaluating the costs and potential benefits of utilizing light-gauge steel for their residential construction. For R-Anell, steel is a technology that may complement or compete with its wood-framed homes. Steel may have advantages in certain markets, such as inner city construction, where steel framing is widely accepted and may be preferred for certain dwelling types. While the company is well positioned to move into steel-framed, single-family or multifamily manufacturing, it views the technology as an alternative where the hurdles are economic, technical, and market acceptance. In these regards, R-Anell is representative of many manufacturers in the nation that depend on wood framing but are wary of the volatility of wood prices and availability and recognize that steel offers compelling advantages for factory builders.

R-Anell is an ideal partner for pioneering steel technology for other reasons, including the fact that it builds both modular and HUD-code homes. By breaking ground with steel on the modular side, R-Anell is following in the footsteps of a few companies in the Northeast that build steel-framed modulars mainly for multistory housing in inner city areas. However, it is ideally positioned to refine the technology in modular construction and then transfer that knowledge to its HUD-code production.

The initial stages of this assessment required R-Anell to develop a steel design equivalent to one of its popular wood-framed homes to serve as a baseline for cost and manufacturing comparisons. By selecting a best selling model for comparison, R-Anell challenged steel technology to replicate many of the more complex details common to high-end homes.

The goals in conducting such a comparison include the following:

- Determine the relative costs of wood and steel-framed designs on a raw material basis. Like QHP, the company recognizes that this is a first generation and the direct comparison is only a rough approximation of the relative costs for the two framing systems.
- Identify major manufacturing costs associated with a switch to steel. This involves an initial assessment of aspects of the design that will slow production and potentially hinder construction quality. As prototypes will be built in later stages, production line issues were identified by R-Anell based on review of the construction drawings.
- Investigate alternative connection systems. Like QHP, R-Anell has focused on connectors as the key to cost-effectiveness and reducing manufacturing time.

The company also recognizes that other issues that affect the viability of steel are not considered in this early stage of product development, thermal performance being among the most challenging. However, solutions exist for meeting the thermal requirements of the International Residential Code and HUD standard, such as exterior rigid board sheathing often used by steel frame builders in the north. While cost prohibitive for the more modestly priced HUD-code homes, rigid sheathing board is widely accepted in the modular and site building markets in the north.

3.2 GENERAL DESIGN CRITERIA

The design criteria for the R-Anell design were taken from the International Residential Code (2000) for the region containing the majority of R-Anell's new home sales. Some of the design parameters included the following:

Design Loads

- Wind: velocity of 120 miles per hour, exposure C
- Roof live load: 30 pounds per square foot (psf)
- Floor live load: 40 psf

Floor Plan

- Box dimensions: 28 x 60 feet, two sections
- Floor joists: 24 inches on center
- Roof pitch: nominal 9 in 12
- Roof trusses: hinged 24 inches on center
- Eaves: 6-inch sidewall overhang
- Marriage line walls: load bearing in each half with 2 x 4-inch nominal studs at 24 inches on center
- Exterior walls 2 x 6-inch nominal studs 24 inches on center

- Habitable attic with two optional dormers and one overframed gable

3.3 DESIGN DEVELOPMENT

The discussions that follow suggest how steel would be used to form the structural system of the R-Anell model. These details have evolved through an iterative design process involving steel engineering specialists and R-Anell engineering and production offices. Each component of the building is discussed separately. A full set of the steel framing details is provided in Appendix A.

3.3.1 Roof

The roof slope for R-Anell's model is 9 in 12 with the truss system designed to provide an additional 780 square feet of habitable space (Figure 3-1) including space provided by two windowed dormers, accessed by stairs from the first floor. R-Anell currently uses a hinged roof truss to build this high sloped roof in the plant and meet height and width restrictions for road transportation. The steel design attempts to provide this same hinged roof system (Figure 3-2).

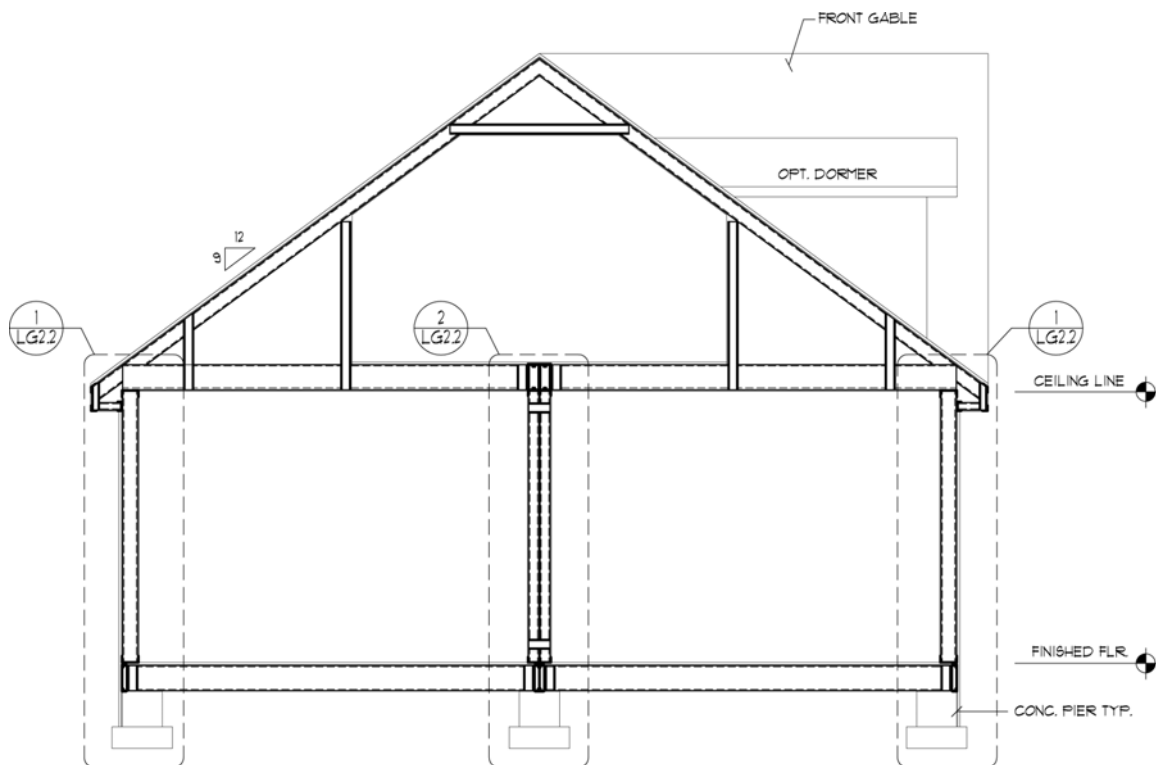


Figure 3-1 Building section

Each roof truss consists of a 9¼-inch deep, 14-gauge bottom chord, a 5½-inch deep, 16-gauge top chord, a 3½-inch deep, 20-gauge collar tie, and two pairs of knee walls utilizing 3½-inch, 18-gauge studs. The bottom chords from each home section end at a continuous boxed beam built up from light-gauge steel members. The chords are connected to the beam with a short section of wall stud in the same fashion as the floor joists are connected to the rim beam.

The top chord is hinged at two locations; one just above the shorter knee wall and the other at the point where the collar tie intersects the chord. The lower hinge allows the roof to fold down to meet the height restriction and the upper hinge allows the top section of the roof to fold back over

itself to meet the width restriction. The short outer knee wall supports the top chord so that the lower hinge pivot point is at the proper height above the bottom chord. The inner knee wall pivots on a hinge to fold down into the vertical position when the roof is lifted, thereby serving as a support for the lifted roof. This allows the crane to be released prior to installation of the many fasteners required to complete the roof assembly. Because crane rental time costs several hundred dollars per hour, it is important to minimize the time it is required at the home site.

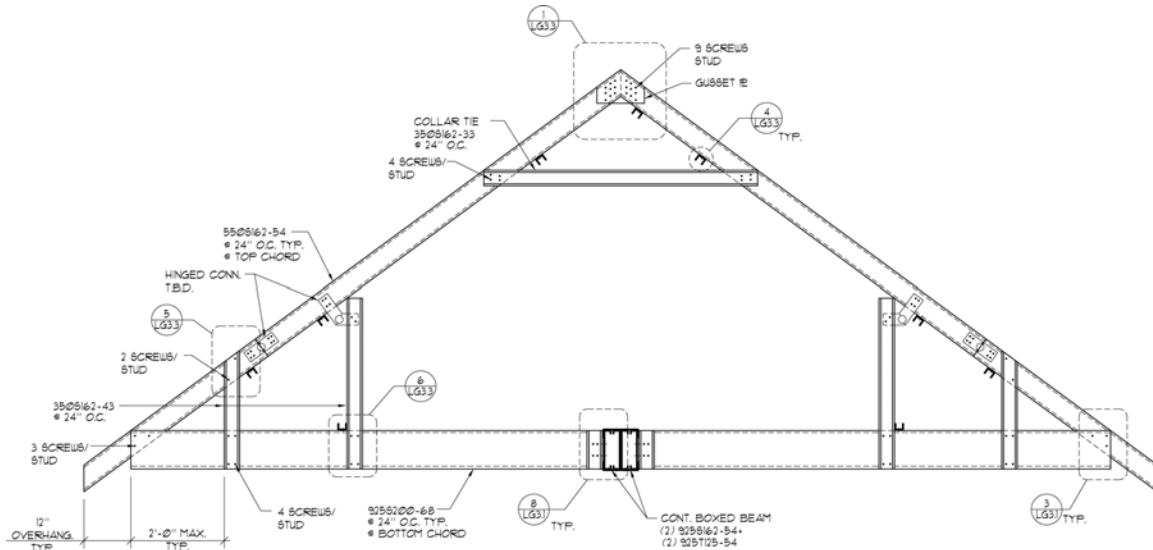


Figure 3-2 Roof truss section

The light-gauge steel hinged roof truss system is one of the components that will require prototyping and testing. Generic details for hinged steel truss sections and the specialized hinge connectors are not readily available, although they may be adaptable from existing wood truss hinge designs. The eccentricity of the steel members (as opposed to symmetrical wood cross-sections) may pose a problem for a steel hinged roof.

The roof design includes a turn-gable constructed of trusses built over the main roof truss system and installed in the field (Figure 3-3).

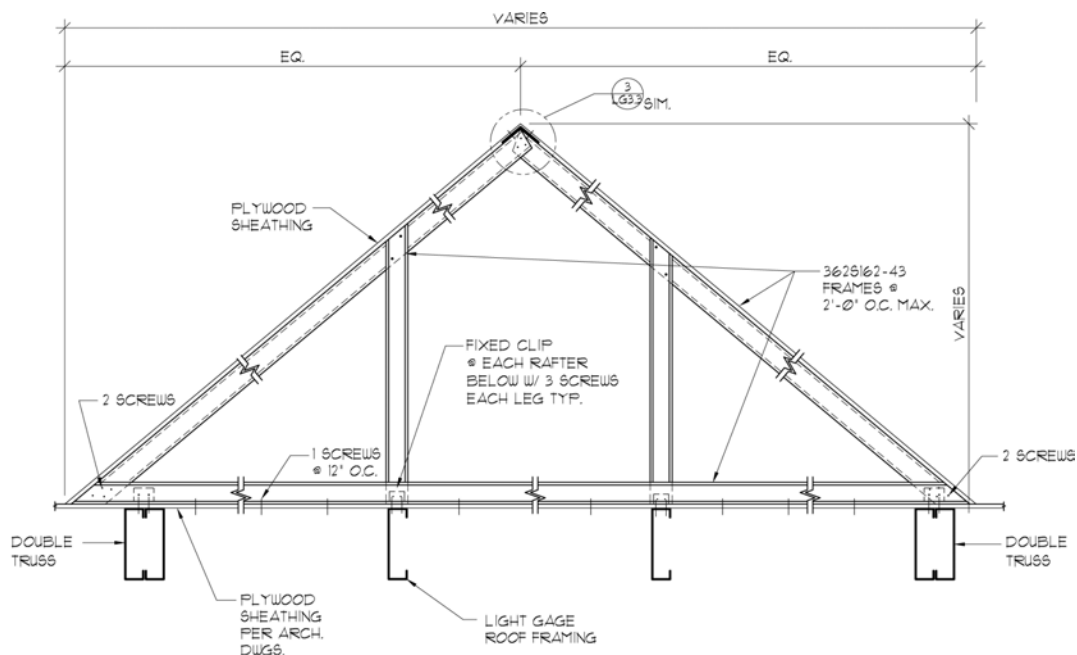


Figure 3-3 Typical overbuild frame detail

Because steel increases in structural efficiency (compared to wood) as spans increase, the short span roof truss may be more economical to build in wood than in steel. The open attic space precludes the typical truss web members and results in the steel members being of a heavier material (14-gauge bottom chords and 16-gauge top chords) than would normally be required for a roof truss of this size. Because of these complications, the design provides the option for using a wood truss as an alternative to steel. It is likely that a hybrid wood/steel design would retain wood framing for the roof system, much as the site builders who pioneered light-gauge steel framing continue to used wood roof framing even after they switched to steel floors and walls.

3.3.2 Walls

Exterior walls are framed with 18-gauge steel studs 5½ inches wide by 1⅝ inches deep spaced 24 inches on center (Figure 3-4). The marriage walls are made of 20-gauge steel studs 3½ inches wide by 1⅝ inches deep on each side of the marriage line. All wall studs are spaced 24 inches on center. No blocking or cross-bracing is required on exterior wall studs.

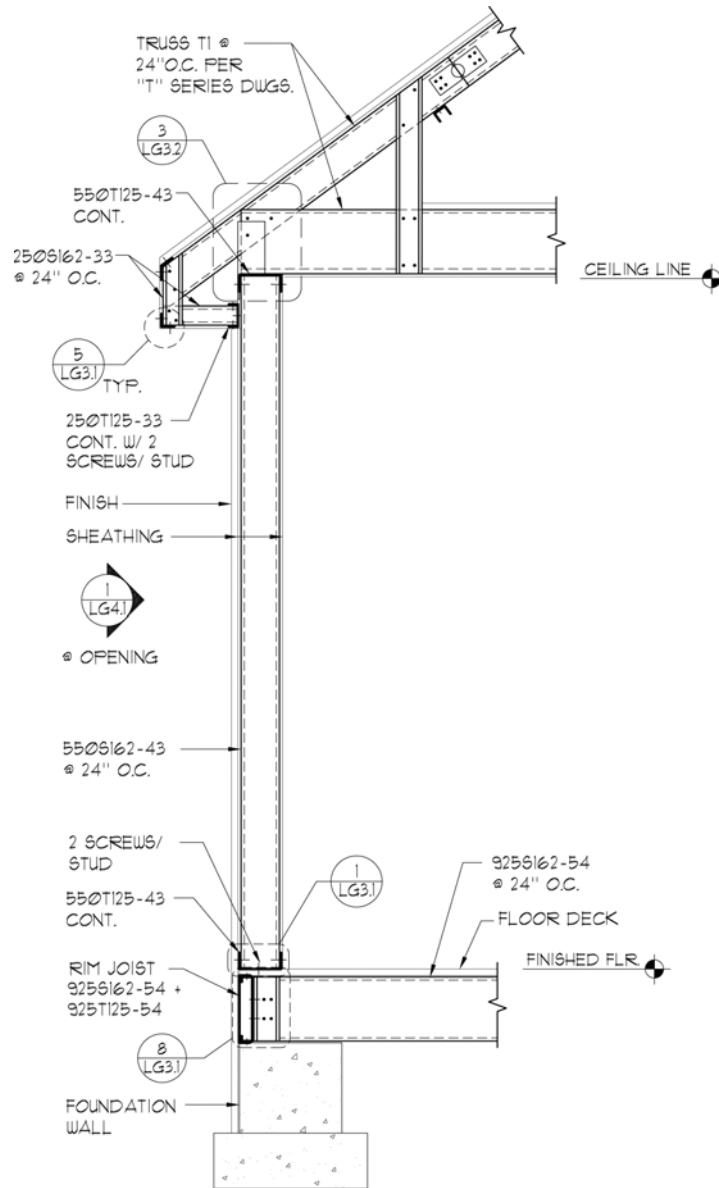


Figure 3-4 Typical section at side wall

Ties between marriage line walls consisting of short sections of wall stud were initially specified at three locations on each stud (Figure 3-5). However, this would preclude installing wallboard on the marriage line walls in the plant. Wall ties were, therefore, limited to locations at marriage line wall openings and ties were added within the floor to connect the rim joists from each half of the home. Lateral stiffness is provided by the wall sheathing consisting of 7/16-inch thick oriented strand board sheathing and gypsum wallboard. Wall studs, roof trusses, and floor joists are aligned vertically, eliminating the need for a structural wall top plate. Only 1¼-inch deep, 18-gauge top and bottom tracks (20 gauge on marriage line walls) are used. Box beams built up from studs and track are used to span marriage wall openings.

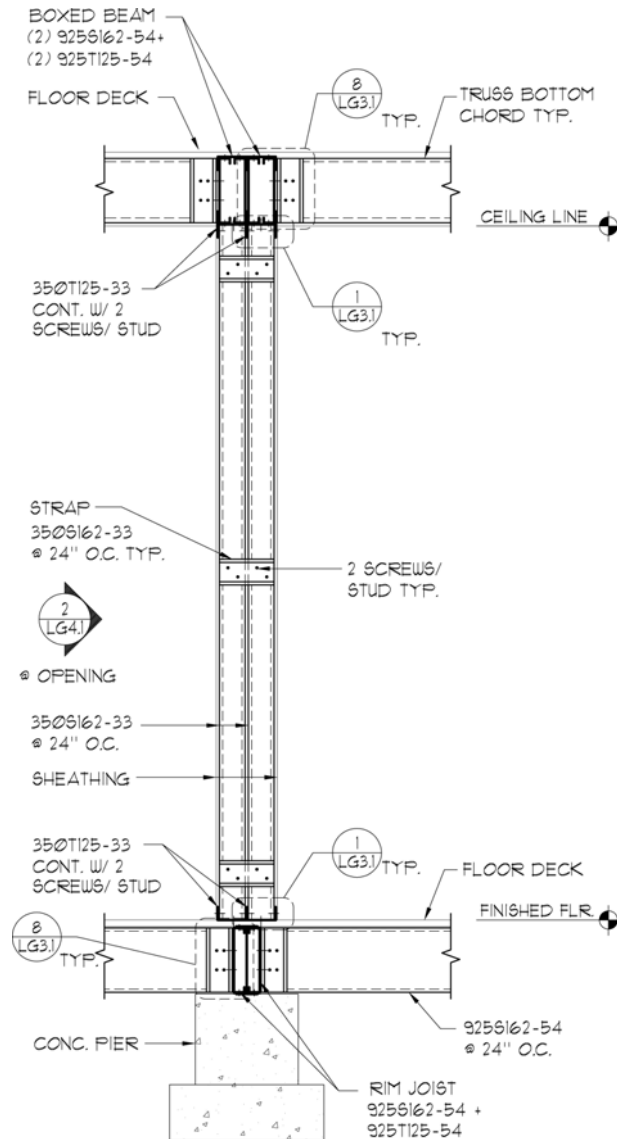


Figure 3-5 Section at marriage wall

R-Anell preferred to use 3½- and 5½-inch wall stud widths for the marriage line walls and exterior walls respectively to maintain the same architectural dimensions of its wood design. Light-gauge steel studs of this width are less common and therefore more costly per foot than the standard 3⅝- and 6-inch wide studs. Were R-Anell to go into full-scale production with steel homes, its production volume may be sufficient to eliminate this cost premium.

3.3.3 Floor system

The floor system consists of 16-gauge steel joists, 9¼ inches deep by 1⅝ inches wide spaced 24 inches on center spanning 13½ feet between rim beams (Figure 3-6) and braced at mid-span (Figure 3-7). The rim beam is made up of a 9¼-inch deep by 1⅝-inch wide 16-gauge stud nested within a joist to form a rectangular box beam. Joists butt into the rim beam and are fastened by a 9¼-inch long 3½-inch wide wall stud screwed to one side of the joist and to the rim beam (Figure 3-8). At end walls and under the stair wall, joists are doubled up with the open sides of the C facing toward each other.

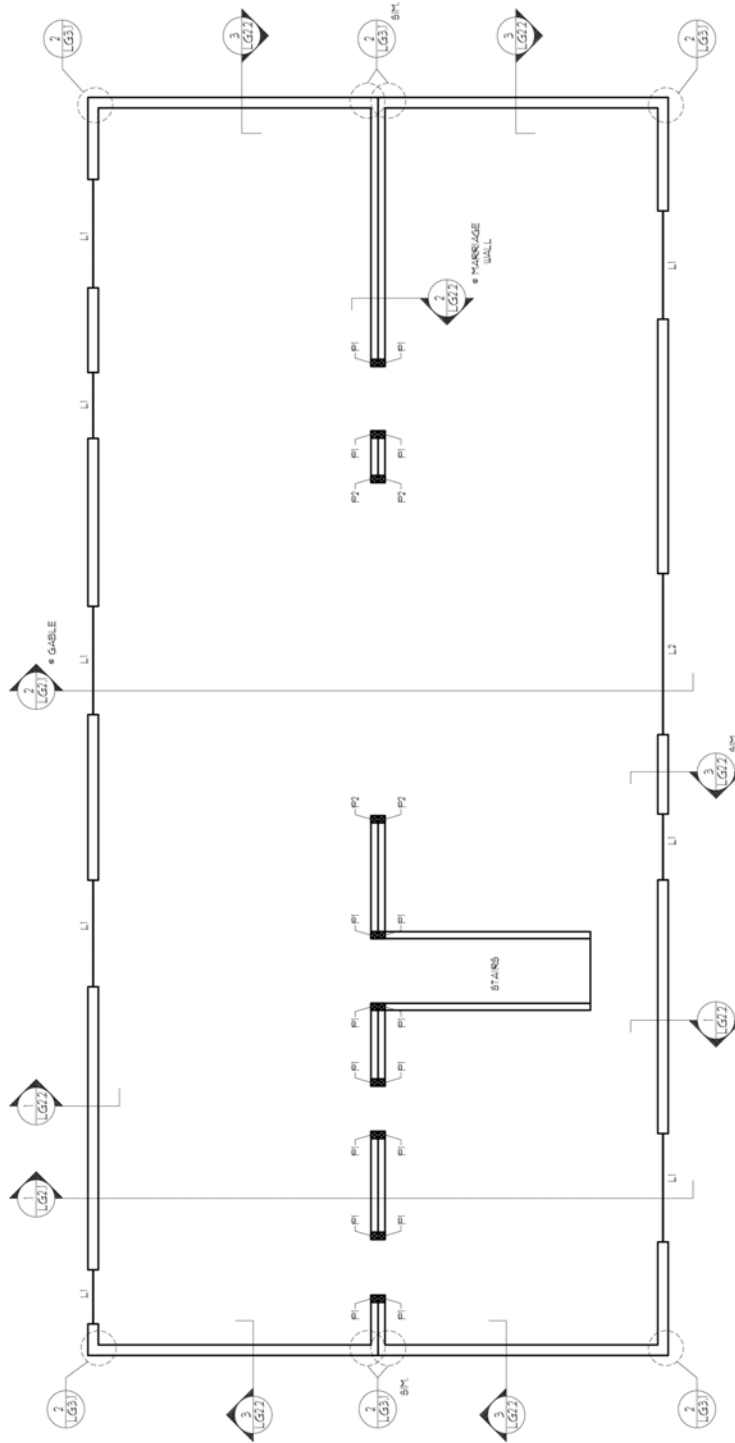


Figure 3-6 First floor wall framing plan

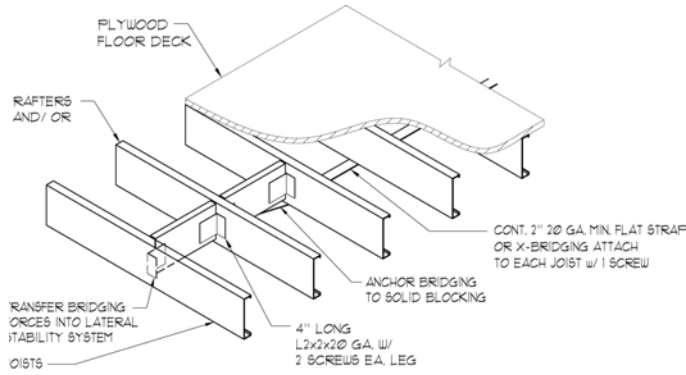


Figure 3-7 Typical floor bracing detail

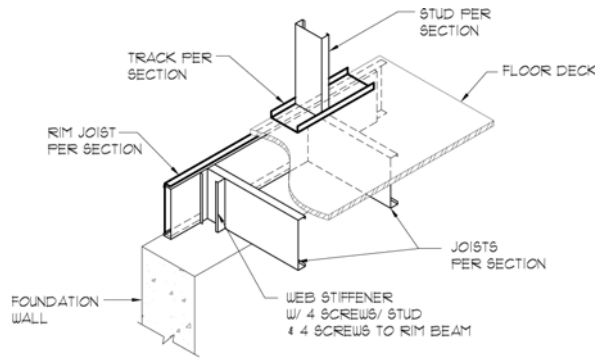


Figure 3-8 Typical rim joist connection detail

3.3.4 Foundation connection

Three strategies for connecting the home to the foundation were discussed as options. The first strategy explored was to screw the rim beam to a 6-inch by 6-inch by 6-inch clip angle fastened to a threaded bolt cast into the concrete pier or foundation (Figure 3-9). To provide the necessary flexibility of placement, the angle would have to be connected through an adjustable slot after the home was set. This would require the bolted and screwed connections to be made from under the home in the crawlspace that may have as little as 20 inches of headroom.

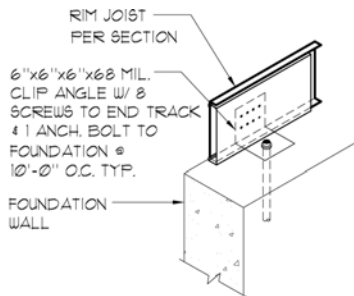


Figure 3-9 Typical detail at foundation edge

A second alternative is to cast a J-bolt with welding plate into concrete and then weld the rim joist to the plate after the home was set. This would have the advantage that no work would be done under the home (except at the marriage line connections for the second home to be set). However, welding is a far more expensive fastening method, particularly when done at the home site. It is also more prone to error and requires unique skills and equipment.

The third and preferred option is to bolt or cast into the foundation a steel strap that would be bent down and away from the bearing surface while the home is being installed and then bent up and screwed into the rim beam from the outside. This version has the advantage of ample installation tolerance, no welding, and no work performed under the home (except for the marriage line of the second half of the home).

The steel design was intended for lifting during installation. It may be lifted by a crane with strapping around the quarter points of the box

3.3.5 Fasteners

A variety of methods are available to fasten light-gauge steel framing members together, including screws, welds, crimping, and even adhesives. The most reliable and cost-effective means for most connections in factory built housing still seems to be the self-tapping screw. They provide a strong, reliable, inexpensive connection and do not require a large investment in equipment. They are, however, labor intensive when numerous screws are required. Including the screws used during field installation and in the plant during fabrication, the R-Anell steel design utilizes an estimated 12,000 screws for light-gauge connections (not including fasteners for applying sheathing). Clearly this is an area that requires attention—both to reduce the number of fasteners and to simplify the fastening system.

3.4 SUGGESTED NEXT STEPS

The technical assistance provided to R-Anell initiated its investigation of steel framing for residential modular construction. This research began the process of describing how this technology may be implemented and identified areas where further research is necessary.

It is anticipated that R-Anell will move forward with product development if the design resulting from the re-engineering effort is cost competitive with traditional wood frame construction. Future efforts may address the following technical issues:

- Development of a hinged roof system using steel members, particularly the hinge detail.
- Fastening options such as welding as an alternative to screws.
- Testing of certain components, such as a steel hinged roof, to demonstrate compliance with applicable standards.
- Development of a two-story design, including framing for stairs and increased structural loads
- Changes to the design requirements that may make the steel design more efficient, such as utilizing more commonly produced 3-5/8- and 6-inch wide studs.

- Determination of what steel components (such as roof trusses and the floor system) are most efficient to produce in the R-Anell plant versus out-sourced to fabricators.
- Development of a thermal solution for the northern regions of R-Anell's market, especially for the floor system when the floor is placed over an unconditioned basement or crawlspace.
- Potential integration of structural steel into the floor system to eliminate light-gauge members and fasteners in the rim joists and make the modules easier to transport.

Important cost, manufacturing, systems integration, and marketing issues must also be addressed:

- In-depth cost analysis for both materials and labor.
- Construction of a full-scale home with steel framing or a wood and steel hybrid design.
- Transportation testing of the full-scale home.
- Process engineering analysis and the design of a prototype manufacturing facility based on the use of steel as the primary structural material. This may include a design for the plant layout tailored to an all-steel design or a steel and wood hybrid.
- Effective methods for training plant staff in the use of steel.
- Research into markets, such as inner cities, that are more likely to be receptive to steel-based manufactured homes.
- Consideration of how the use of steel for much of a home's structural framework will engender changes in the use of sheathing and other materials that attach to the home's frame.

APPENDIX A
R-ANELL DRAWINGS

Steel Framing Prototype Development: Final Report

GENERAL NOTES:

1. THESE DRAWINGS ARE FOR THE FABRICATION AND ERECTION OF THE LIGHT GAGE FRAMING SYSTEM ONLY.
2. THE LIGHT GAGE FRAMING MATERIALS ARE MANUFACTURED BY ANY SSMA MEMBER MANUFACTURER IN ACCORDANCE WITH ASTM C955. MATERIAL SIZES AND GAUGES ARE INDICATED ON THE DRAWINGS. ALL LIGHT GAGE MEMBERS SHALL BE MANUFACTURED FROM SHEET STEEL AND GALVANIZED IN ACCORDANCE WITH ASTM A1003, FORMERLY A653, A924, A525 AND A446, WITH A MINIMUM G 60 COATING.
3. THE MINIMUM YIELD STRENGTH OF THE LIGHT GAGE FRAMING COMPONENTS SHALL BE AS FOLLOWS:
 - a) 16 GAGE (54 MILS) OR HEAVIER - MINIMUM 50,000 PSI
 - b) 18 GAGE (43 MILS) OR LIGHTER - MINIMUM 33,000 PSI UNLESS NOTED OTHERWISE
 - c) ALL TRACKS & ACCESSORIES - MINIMUM 33,000 PSI UNLESS NOTED OTHERWISE
 - d) ALL TRUSS AND RAFTER MEMBERS 16 GAGE (54 MILS) OR HEAVIER TO BE MINIMUM 50,000 PSI
 - e) ALL TRUSS AND RAFTER MEMBERS 18 GAGE (43 MILS) OR LIGHTER TO BE MINIMUM 50,000 PSI
4. THE LIGHT GAGE WALL STUDS AND FLOOR JOISTS SHALL BE PUNCHED
ALL TRUSS AND RAFTER MEMBERS SHALL BE UNPUNCHED.
5. THE LIGHT GAGE FRAMING HAS BEEN DESIGNED IN ACCORDANCE WITH THE FOLLOWING CODES, LOADS AND SPECIFICATIONS:
 - a) IRC 2000
 - b) ANSI/ASCE 7-98
 - c) WIND LOAD: $V=120$ MPH, $I=1.0$, EXPOSURE C
 - d) SNOW LOAD: $P_g=20$ PSF, $C_e=0.7$, $I=1.0$
 - e) LIVE LOAD: ROOF=30 PSF, FLOOR=40 PSF
 - f) AISI "SPECIFICATIONS FOR DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS"-1996
6. THIS SUBMITTAL IS SUBJECT TO THE REVIEW OF THE PROJECT ARCHITECT AND ENGINEER OF RECORD. LIGHT GAGE MEMBER SIZES AND CONNECTION DETAILS MAY DIFFER FROM THE PROJECT CONSTRUCTION DOCUMENTS.
7. UNLESS NOTED OTHERWISE, THE FOLLOWING ITEMS SHOWN ON THE LIGHT GAGE PLANS, DETAILS AND SECTIONS ARE SHOWN FOR REFERENCE ONLY AND ARE DESIGNED, BY OTHERS:
 - FOUNDATIONS AND GRADE SLABS
 - STRUCTURAL CONCRETE SLABS
 - VENEERS, TIES AND CONTROL JOINTS
 - FLOOR AND ROOF DECKING
 - TIMBER FRAMING

REFER TO THE ARCHITECTURAL AND STRUCTURAL CONSTRUCTION DOCUMENTS FOR DETAILS OF THE ITEMS LISTED ABOVE THAT ARE NOT FULLY DETAILED ON THESE DRAWINGS.
8. DESIGN VERIFICATION OF THE PRIMARY STRUCTURAL SYSTEM TO SUPPORT THE LOADS IMPOSED BY THE LIGHT GAGE FRAMING IS BY OTHERS UNLESS NOTED OTHERWISE ON THE LIGHT GAGE DRAWINGS.
9. REFER TO THE LIGHT GAGE ENGINEERING CALCULATIONS FOR ADDITIONAL DESIGN INFORMATION.
10. REFER TO THE APPROVED CONSTRUCTION DOCUMENTS FOR DIMENSIONS AND ELEVATIONS NOT INDICATED ON THESE DRAWINGS.
11. ALL CONNECTIONS SHALL BE WELDED, SCREWED OR POWDER FASTENED AS INDICATED ON THESE DRAWINGS.

WELDS - ALL WELDED CONNECTIONS SHALL BE PERFORMED IN ACCORDANCE WITH THE LATEST EDITION OF THE AWS D1.3 SPECIFICATION FOR WELDING SHEET STEEL IN STRUCTURES. ALL WELDING SHALL BE PERFORMED BY AWS CERTIFIED WELDERS. ALL WELDS SHALL BE CLEANED AND COATED WITH RUST INHIBITIVE ZINC PAINT.

Steel Framing Prototype Development: Final Report

SCREWS - #10 SELF DRILLING SCREWS MANUFACTURED BY GRABBER OR HILTI AND INSTALLED PER THE FASTENER MANUFACTURER'S SPECIFICATIONS. MINIMUM 1/2" LENGTH FOR LIGHT GAGE TO LIGHT GAGE CONNECTIONS. (MINIMUM 1-1/2" LENGTH FOR LIGHT GAGE TO TIMBER CONNECTIONS.) SCREWS SHALL BE SPACED A MINIMUM OF 1/2" BETWEEN ADJACENT SCREWS AND FROM METAL EDGES.

POWDER ACTUATED FASTENERS (P.A.F.) - ϕ .138" MINIMUM SHANK DIAMETER P.A.F. MANUFACTURED BY RAMSET OR HILTI AND INSTALLED PER THE FASTENER MANUFACTURER'S SPECIFICATIONS.

PROVIDE MINIMUM 1-1/4" LONG P.A.F. FOR LIGHT GAGE CONNECTIONS TO CONCRETE. P.A.F. IN CONCRETE SHALL BE SPACED A MINIMUM OF 4" BETWEEN ADJACENT P.A.F. AND A MINIMUM OF 3" FROM CONCRETE EDGES. MINIMUM P.A.F. EMBEDMENT IN CONCRETE SHALL BE 1-1/8".

PROVIDE MINIMUM 1/2" LONG P.A.F. WITH KNURLED SHANKS FOR LIGHT GAGE CONNECTIONS TO STRUCTURAL STEEL. P.A.F. SHALL BE SPACED A MINIMUM 1-1/2" BETWEEN ADJACENT P.A.F. IN STRUCTURAL STEEL AND A MINIMUM 1/2" FROM STEEL EDGES. THE P.A.F. POINT SHALL BE DRIVEN COMPLETELY THROUGH THE BACK SIDE OF THE STRUCTURAL STEEL MEMBER.

MASONRY ANCHORS - 1/4" DIAMETER x 2" LONG SELF DRILLING SCREW ANCHORS MANUFACTURED BY RAMSET (TAPCON) OR HILTI (KWIK CON II) AND INSTALLED PER THE FASTENER MANUFACTURER'S SPECIFICATIONS FOR LIGHT GAGE CONNECTIONS TO CONCRETE MASONRY.

DRIVE-IN EXPANSION ANCHORS (MUSHROOM HEAD) - 1/4" DIAMETER x 1-1/4" LONG ZAMAC NAILIN BY RAWL, METAL HIT BY HILTI OR HAMMER SET BY RAMSET AND INSTALLED PER THE MANUFACTURER'S SPECIFICATIONS. ANCHORS IN CONCRETE SHALL BE SPACED A MINIMUM OF 4" BETWEEN ADJACENT ANCHORS AND A MINIMUM OF 3" FROM CONCRETE EDGES. MINIMUM ANCHOR EMBEDMENT IN CONCRETE SHALL BE 1-1/8".

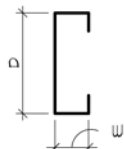
EXPANSION ANCHORS - PROVIDE MINIMUM 3/8" DIAMETER KWIK BOLT II EXPANSION ANCHORS BY HILTI OR EQUAL, WITH A MINIMUM 2-1/2" EMBEDMENT INTO CONCRETE. MINIMUM SPACING BETWEEN ADJACENT EXPANSION ANCHORS TO BE 5". EXPANSION ANCHORS SHALL BE LOCATED A MINIMUM OF 3" FROM CONCRETE EDGES. USE OVERSIZE WASHERS FOR ATTACHING LIGHT GAGE WITH EXPANSION ANCHORS. INSTALL PER THE MANUFACTURER'S SPECIFICATIONS FOR LIGHT GAGE CONNECTIONS TO CONCRETE.

12. ALL MEMBERS SHALL BE CUT SQUARELY FOR ATTACHMENT TO PERPENDICULAR MEMBERS OR SLOPE CUT AS REQUIRED FOR AN ANGULAR FIT AGAINST ABUTTING MEMBERS.
13. FIELD CUTTING OF LIGHT GAGE MEMBERS SHALL BE DONE BY SAWING OR SHEARING. TORCH CUTTING OF LIGHT GAGE MEMBERS IS NOT PERMITTED.
14. DO NOT CUT OR SPLICE LIGHT GAGE FRAMING MEMBERS UNLESS INDICATED BY THESE DRAWINGS.
15. DO NOT BEAR OR CONNECT LIGHT GAGE MEMBERS WITHIN TWELVE INCHES OF THE PUNCHED OPENINGS IN THE MEMBER WEBS UNLESS THE MEMBERS ARE REINFORCED WITH A MINIMUM 18" LONG UNPUNCHED TRACK OR STUD AT THE PUNCH OPENING. THE TRACK OR STUD REINFORCING PIECE SHALL BE THE SAME SIZE AND GAGE AS THE PUNCHED MEMBER. FASTEN THE REINFORCING PIECE TO THE MEMBER WITH A MINIMUM OF FOUR SCREWS.
16. THE LIGHT GAGE FRAMING HAS BEEN DESIGNED TO SUPPORT THE LOADS INDICATED IN THE CALCULATIONS. ADDITIONAL TEMPORARY BRACING AND SHORING SHALL BE PROVIDED AS REQUIRED TO STABILIZE THE FRAMING AND TO SUPPORT CONSTRUCTION LOADS. TEMPORARY BRACING SHALL REMAIN IN PLACE UNTIL PERMANENT BRACING IS INSTALLED AND/OR ADDITIONAL CONSTRUCTION LOADS ARE REMOVED.
17. THE CONTRACTOR SHALL PROVIDE LIGHT GAGE MEMBERS AT THE SIZE AND SPACING INDICATED ON THESE DRAWINGS. LARGER SIZES AND/OR CLOSER SPACING MAY BE SUBSTITUTED PROVIDED THE SUBSTITUTIONS ARE COORDINATED WITH THE PROJECT ARCHITECTURAL AND STRUCTURAL DRAWINGS.

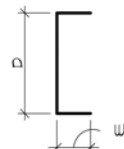
Steel Framing Prototype Development: Final Report

18. THESE DRAWINGS ARE INTENDED TO INDICATE THE MEMBER SIZES AND CONNECTIONS RELEVANT TO THE LIGHT GAGE FRAMING. THESE SHOP DRAWINGS ARE NOT INTENDED TO BE 'DIMENSIONED' DRAWINGS AND SHOULD NOT BE USED FOR MATERIAL TAKE-OFFS. REFER TO THE ARCHITECTURAL DRAWINGS FOR REQUIRED MEMBER LENGTHS.
19. SHEATHING ON THE LIGHT GAGE FRAMING SHALL BE INSTALLED AS INDICATED IN THE PROJECT CONSTRUCTION DOCUMENTS AND SPECIFICATIONS AND PER ASTM C955.
20. UNLESS OTHERWISE NOTED, THIS SUBMITTAL DOES NOT INCLUDE THE DESIGN AND DETAILING FOR THE INTERIOR LIGHT GAGE FRAMING.
21. ALL CONSTRUCTION SHALL BE IN ACCORDANCE WITH O.S.H.A. STANDARDS.
22. LIGHT GAGE JOISTS, RAFTERS AND TRUSSES SHALL ALIGN OVER BEARING WALL STUDS UNLESS DETAILED OTHERWISE IN THE SHOP DRAWINGS.

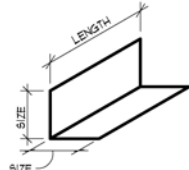
TYPICAL LIGHT GAGE MEMBER DESIGNATION LEGEND (EXAMPLE ONLY)



TYPICAL STUD AND RAFTER



TYPICAL TRACK




TYPICAL ANGLE

MEMBERS ARE DESIGNATED ON THIS SHOP DRAWING AS FOLLOWS:

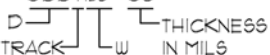
33 MILS = 20 GA.
 43 MILS = 18 GA.
 54 MILS = 16 GA.
 68 MILS = 14 GA.
 91 MILS = 12 GA.

STUDS AND RAFTERS - 600S162 - 68



 D = STUD W = TRACK THICKNESS IN MILS

TRACKS - 600T125 - 68



 D = TRACK W = TRACK THICKNESS IN MILS

ANGLES - $\angle 3 \times 3 \times 68 \times 4\frac{1}{2}$

SIZE MILS LENGTH (INCHES)

125 = 1.25" = 1¼"	250 = 2.5" = 2½"	550 = 5.5" = 5½"
137 = 1.37" = 1⅜"	300 = 3.0" = 3"	600 = 6.0" = 6"
162 = 1.62" = 1⅝"	362 = 3.62" = 3⅞"	725 = 7.25" = 7¼"
200 = 2.00" = 2"	400 = 4.0" = 4"	800 = 8.0" = 8"

THE LEGEND NOTED ABOVE IS AN EXAMPLE OF HOW TO READ THE STEEL STUD MANUFACTURERS ASSOCIATION (SSMA) LIGHT GAGE MEMBER DESIGNATIONS. ACTUAL STUD SIZES, TRACK SIZES AND MIL THICKNESSES REQUIRED FOR THIS PROJECT ARE NOTED ON THE ENCLOSED PLANS, SECTIONS AND DETAILS.

TYPICAL LIGHT GAGE ABBREVIATIONS

<p>‡ = AND @ = AT ⊕ = CENTER LINE ARCH. = ARCHITECTURAL C.R.C. = COLD ROLLED CHANNEL CONC. = CONCRETE C.M.U. = CONCRETE MASONRY UNIT CONT. = CONTINUOUS DEFL. = DEFLECTION ∅ = DIAMETER DWG. = DRAWINGS ELEV. = ELEVATION EQ. = EQUAL EXIST. = EXISTING FLR. = FLOOR</p>	<p>MAX. = MAXIMUM MFR. = MANUFACTURER MTL. = METAL MIN. = MINIMUM O.C. = ON CENTER P.A.F. = POWDER ACTUATED FASTENERS PL. = PLATE ± = PLUS OR MINUS REQ'D = REQUIRED SIM. = SIMILAR T.O.S. = TOP OF STEEL TYP. = TYPICAL UNO. = UNLESS NOTED OTHERWISE V.S.C. = VERTICAL SLIP CLIP W/ = WITH</p>
--	--

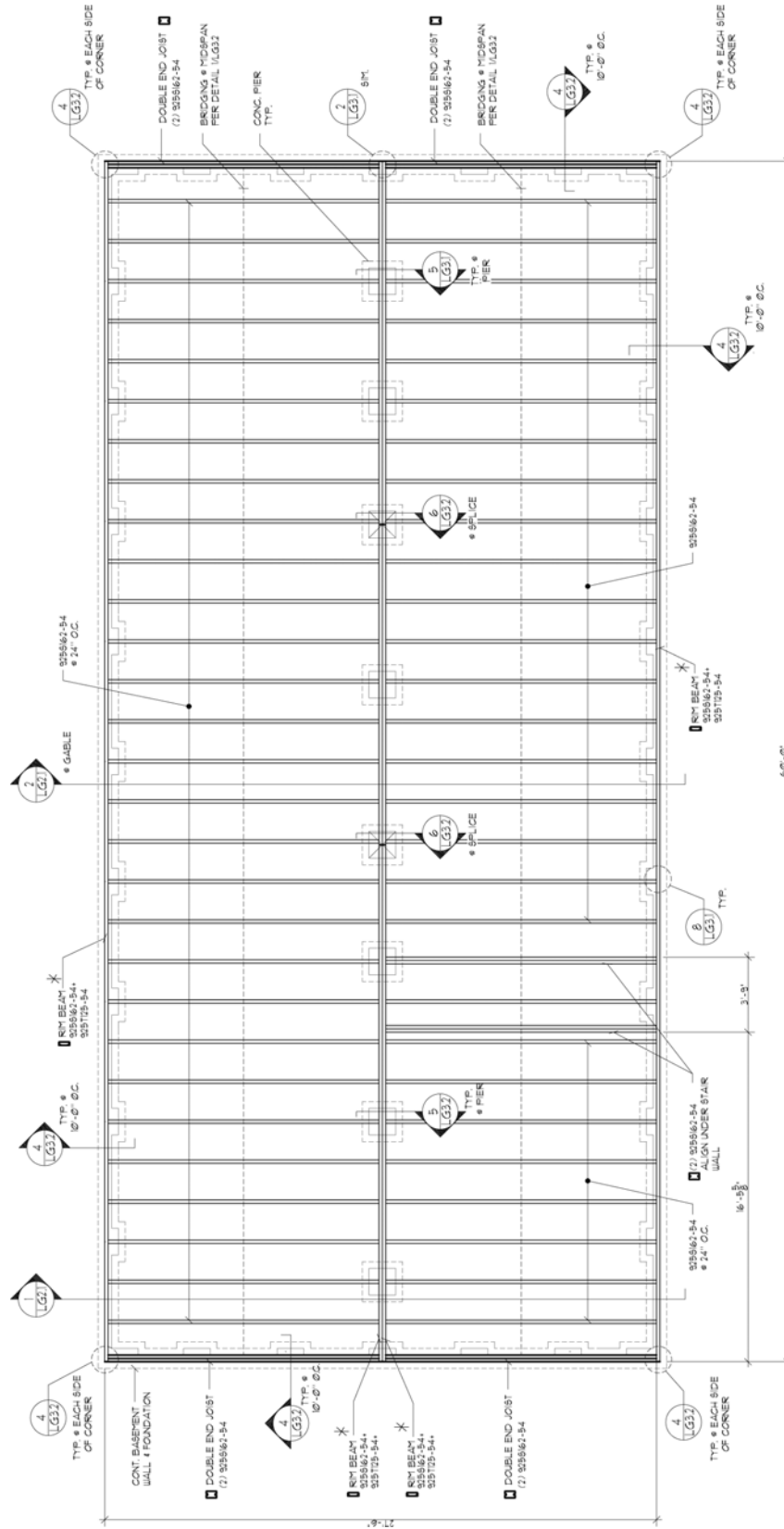


Figure A-1 First floor framing plan

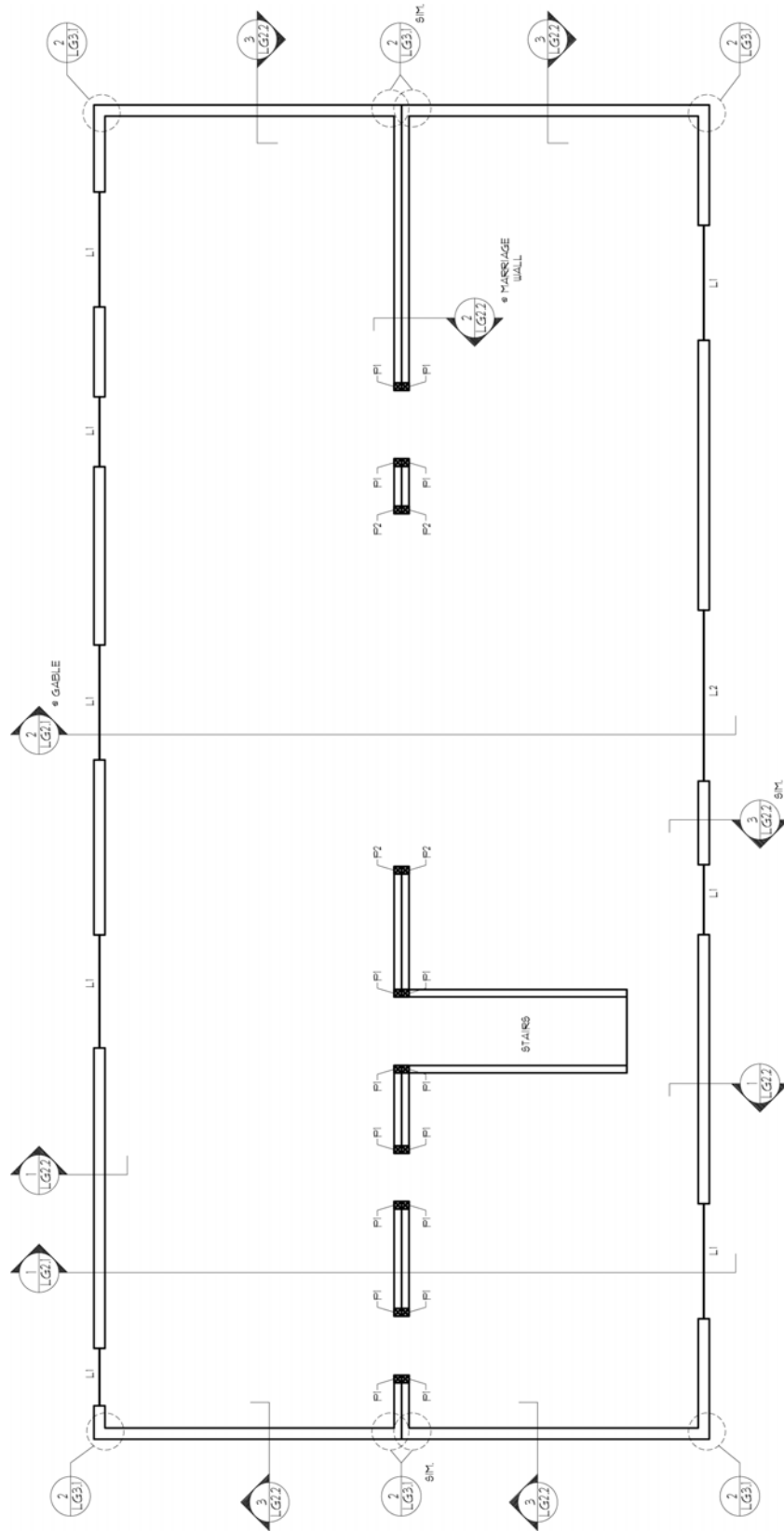


Figure A-2 First floor wall framing plan

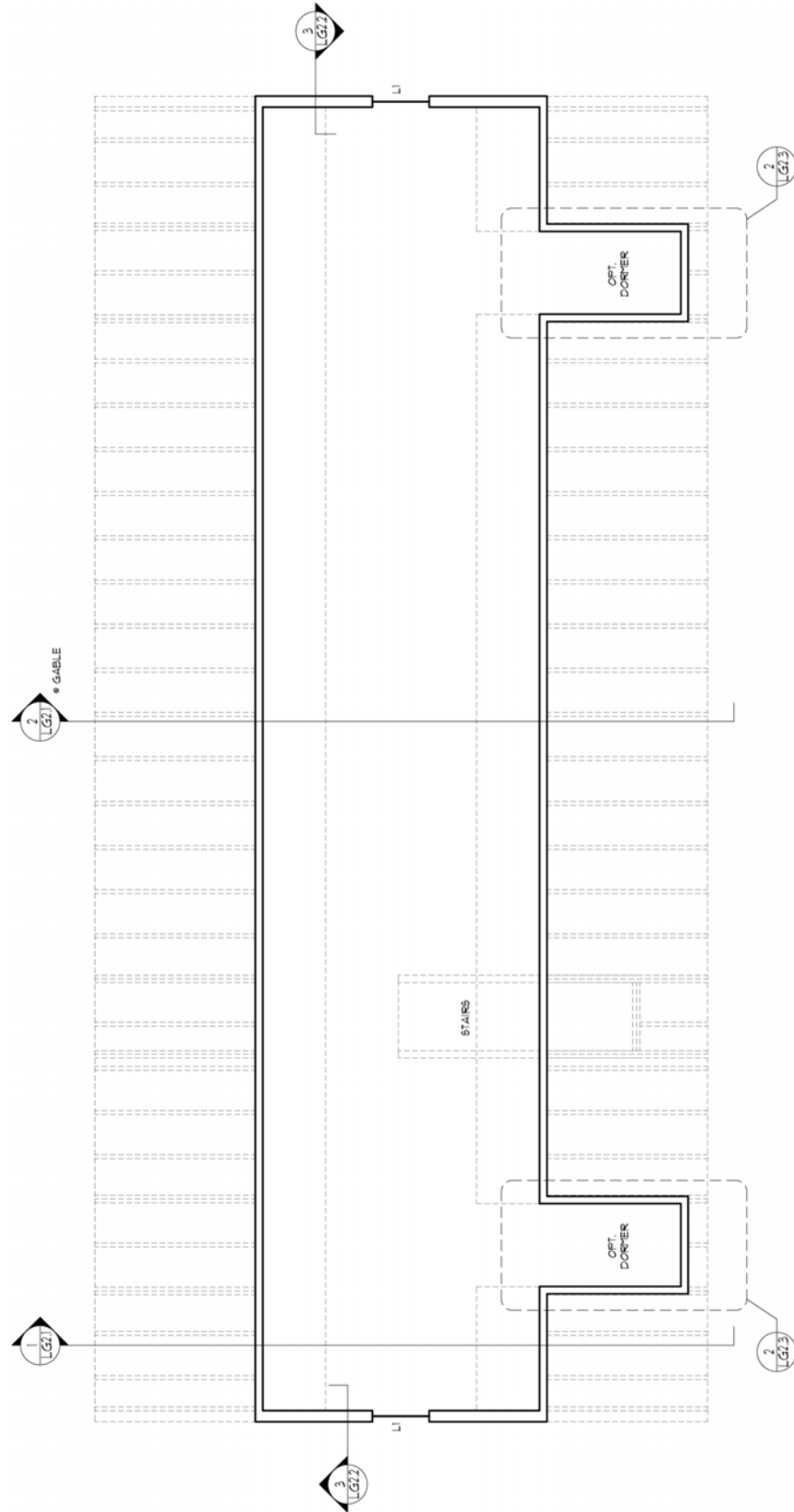


Figure A-4 Second floor wall framing plan

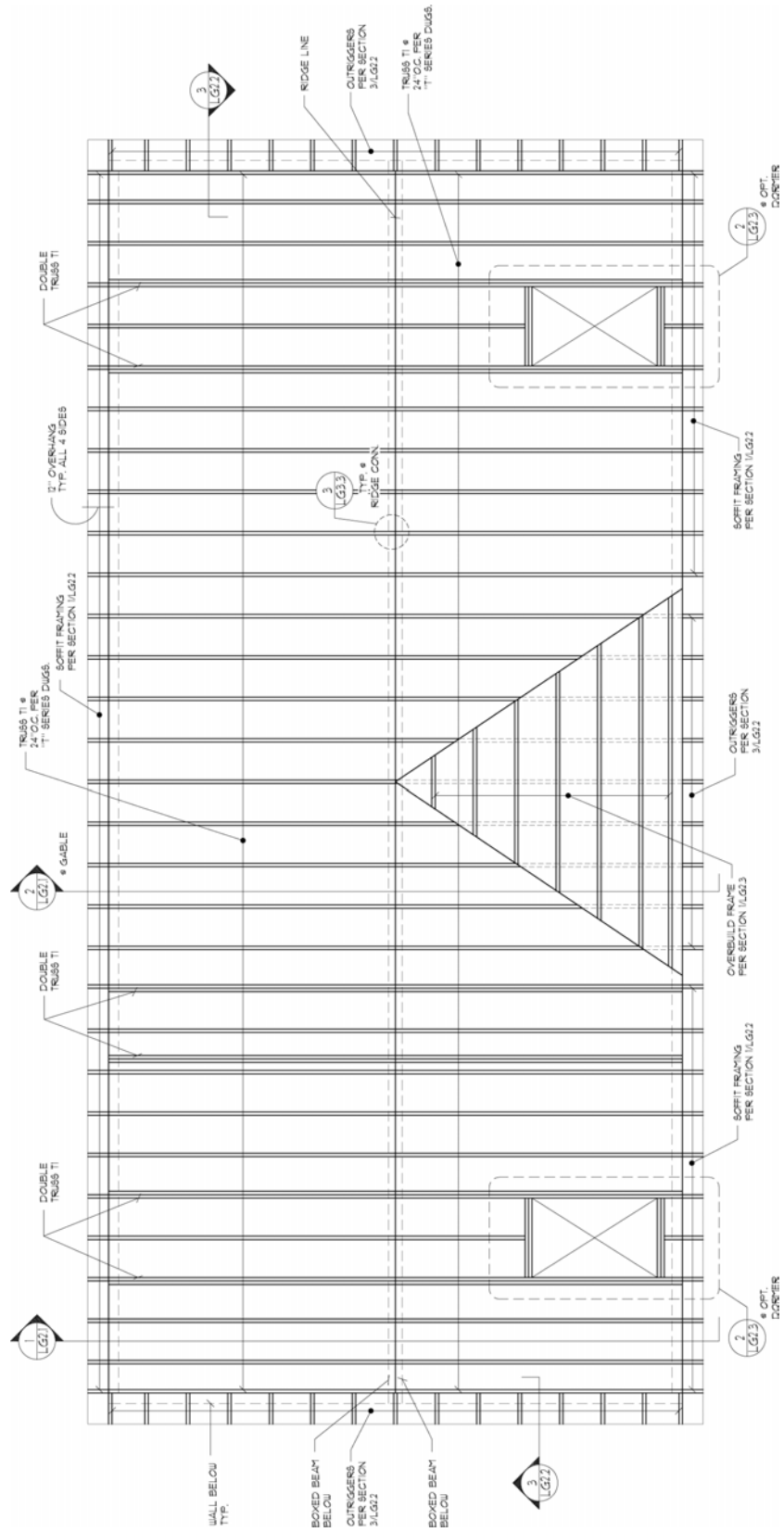


Figure A-5 Roof framing plan at truss top chord

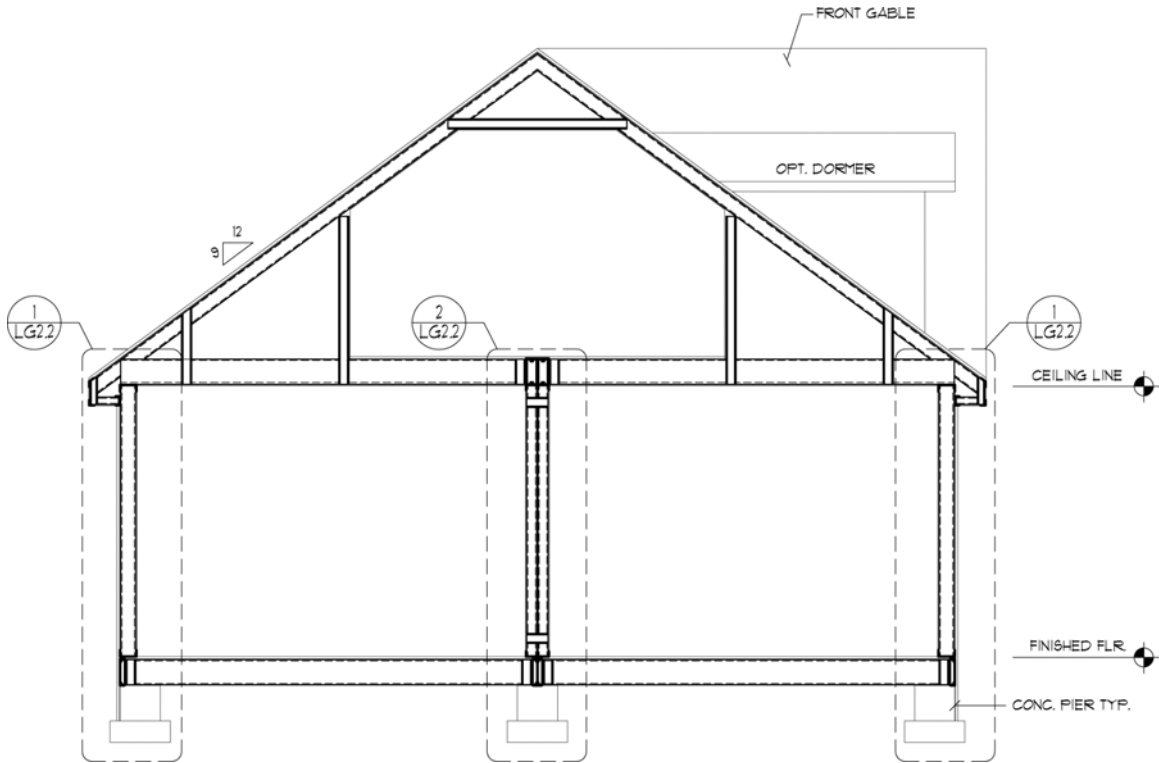


Figure A-6 Building section

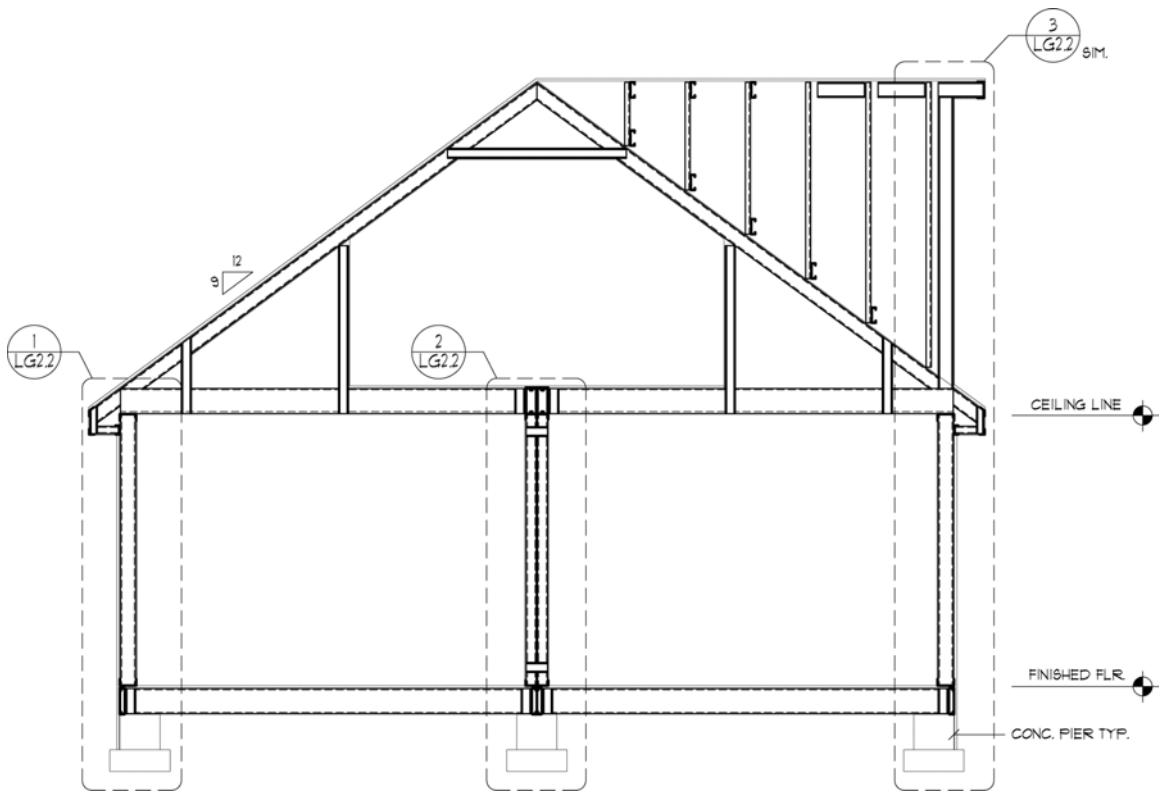


Figure A-7 Building section at front gable

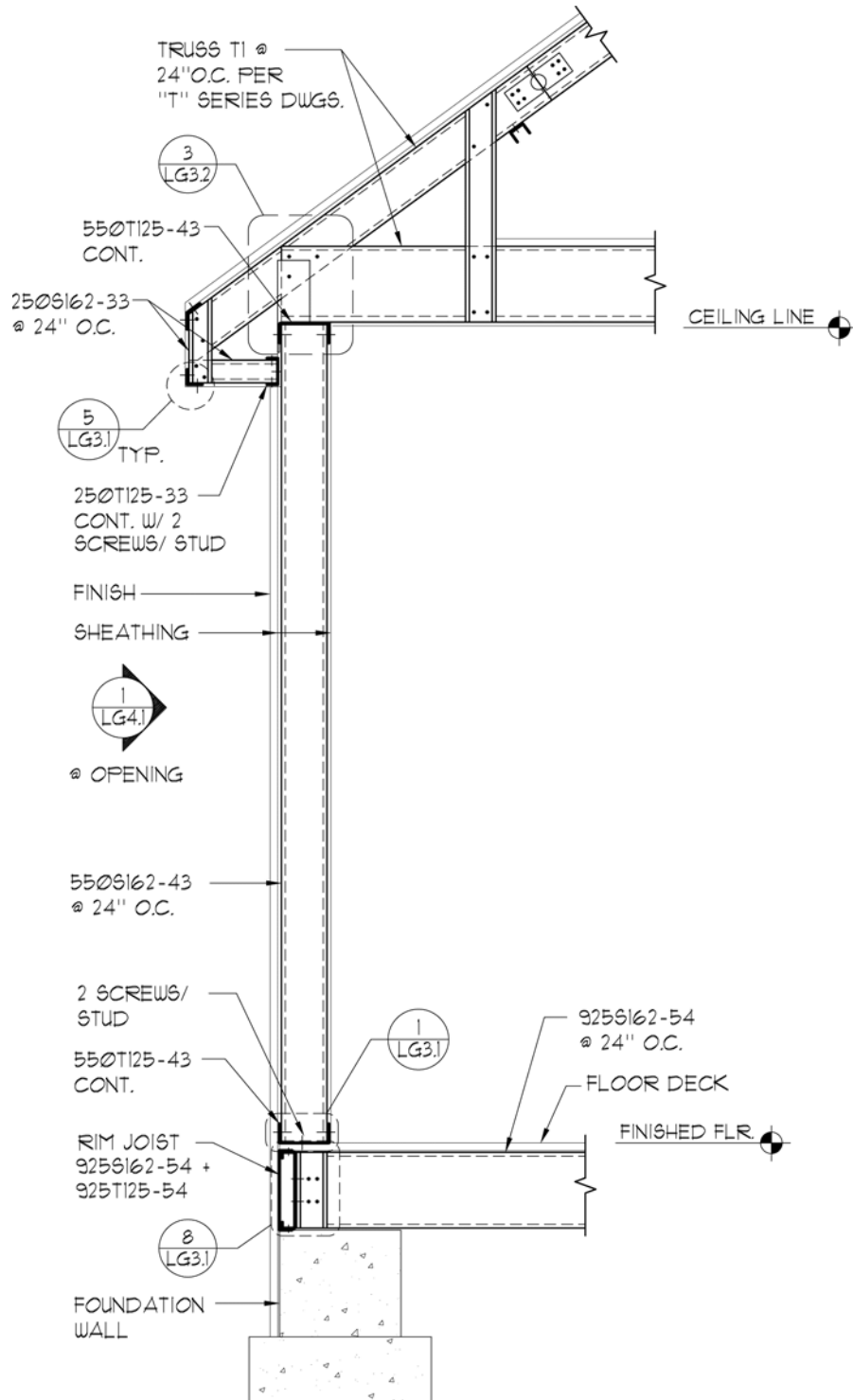


Figure A-8 Typical section at side wall

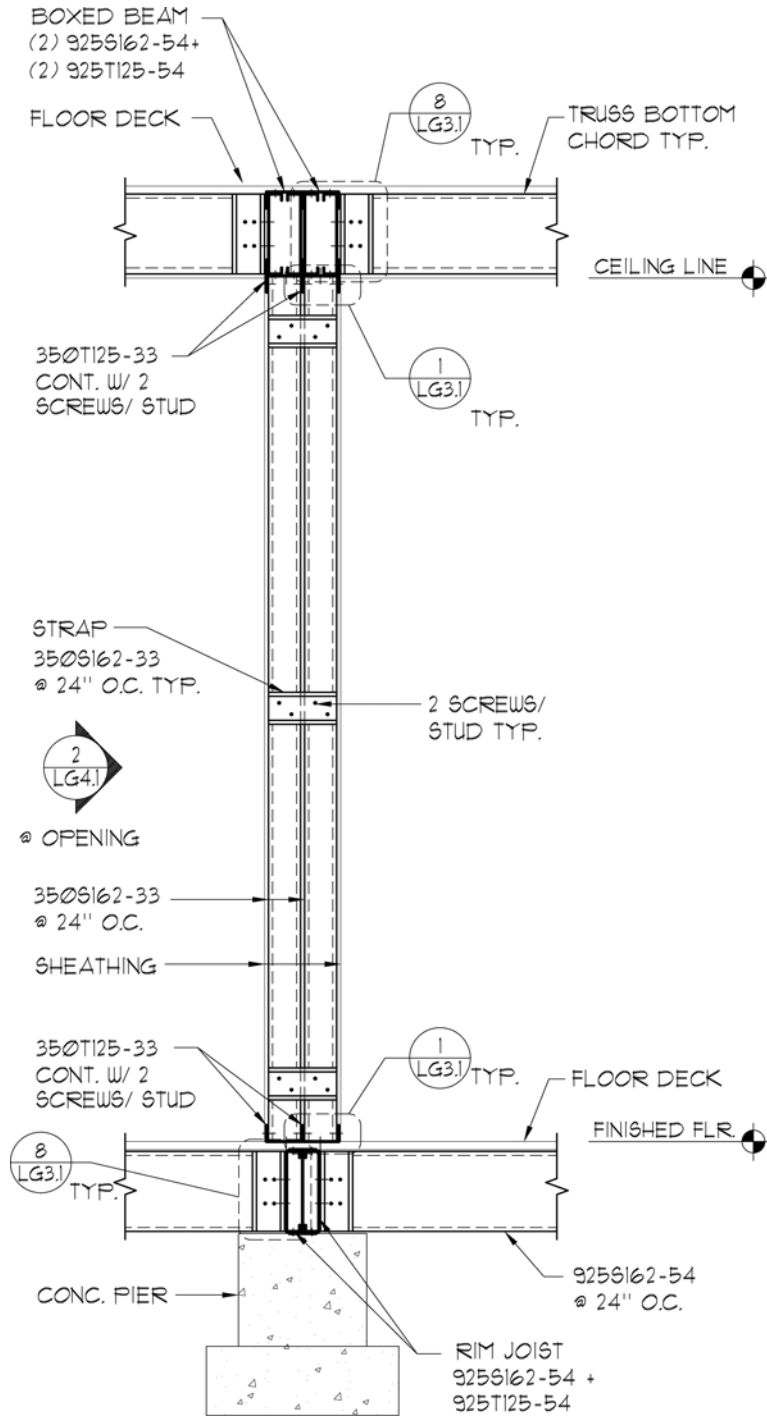


Figure A-9 Section at marriage wall

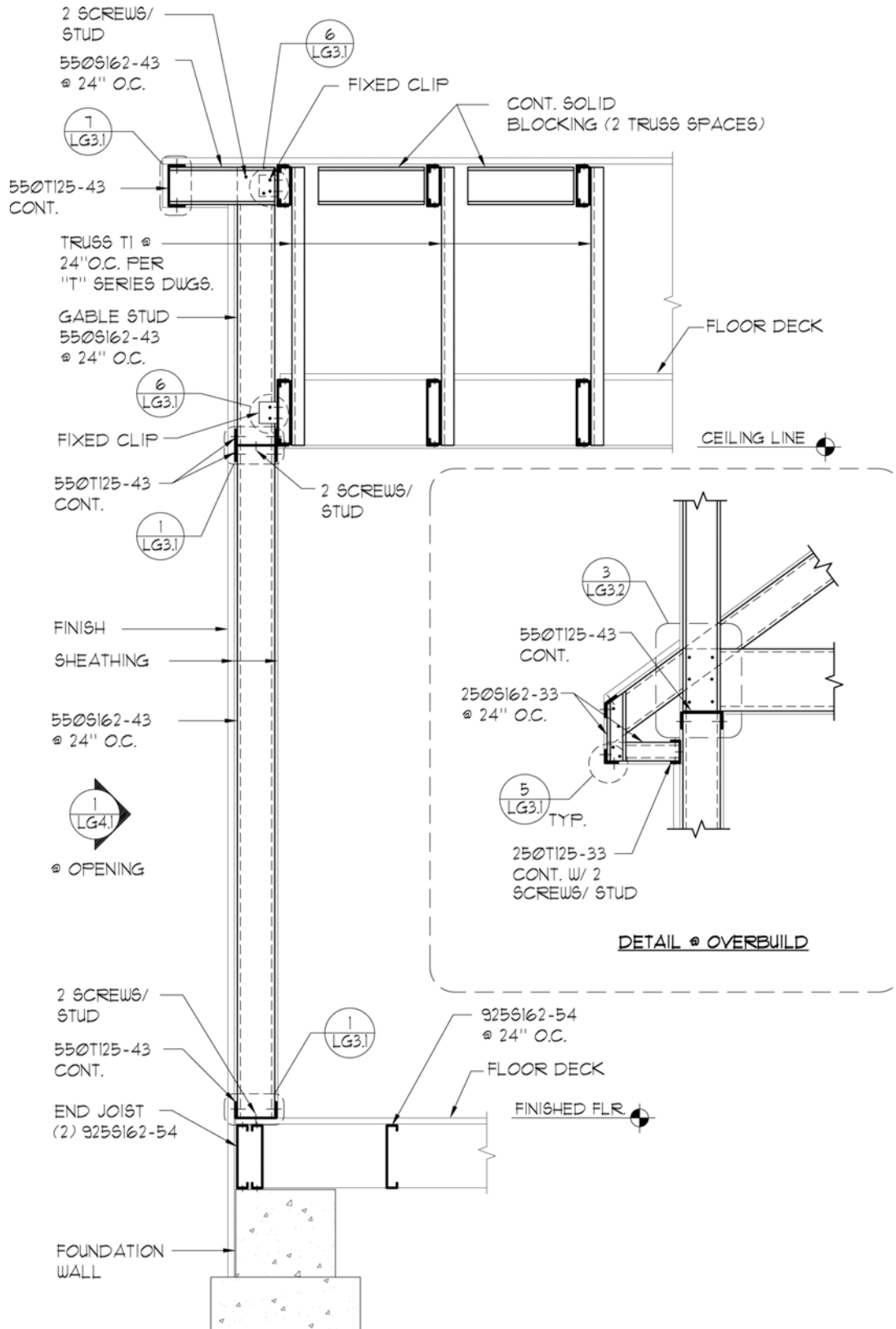


Figure A-10 Typical section at gable end

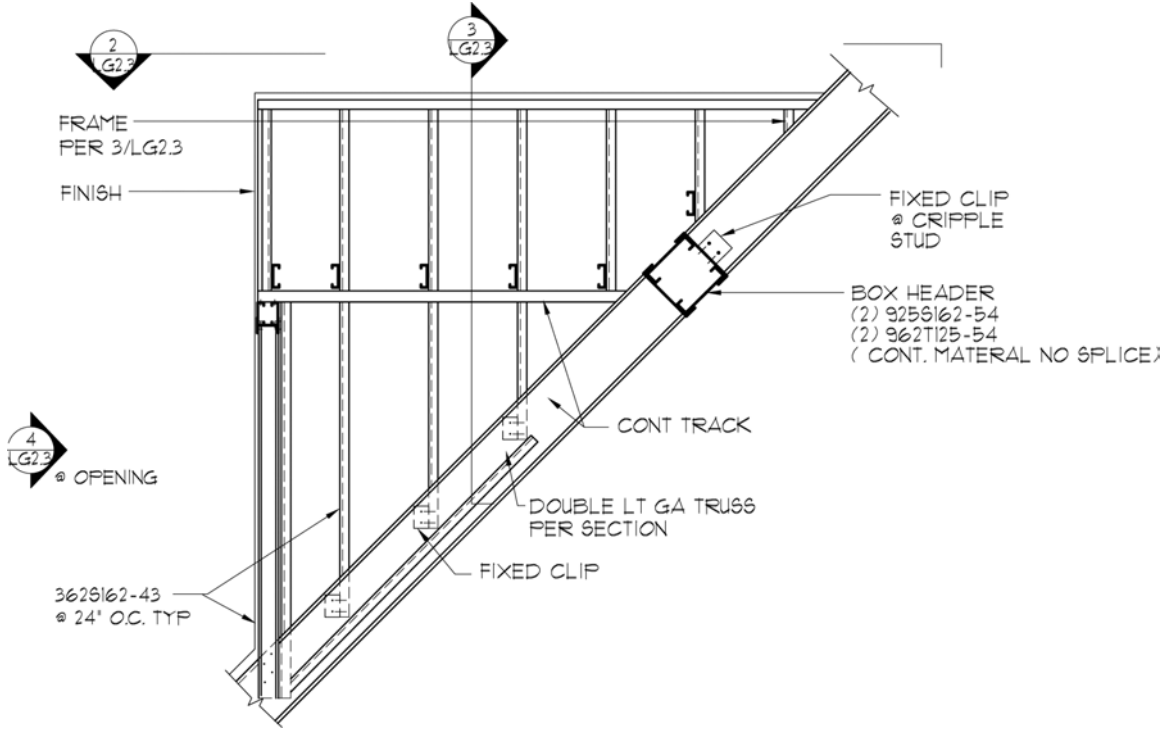


Figure A-11 Dormer section

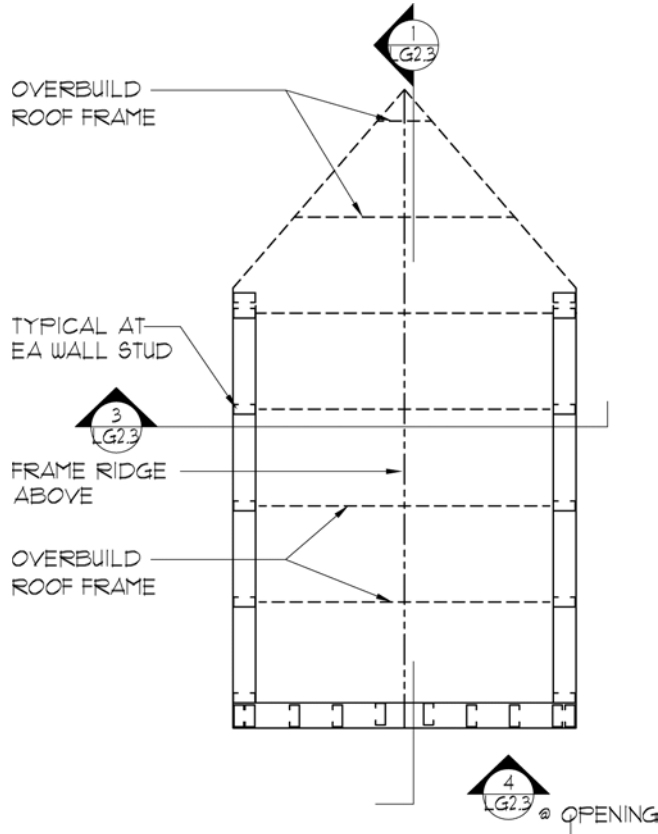


Figure A-12 Dormer plan

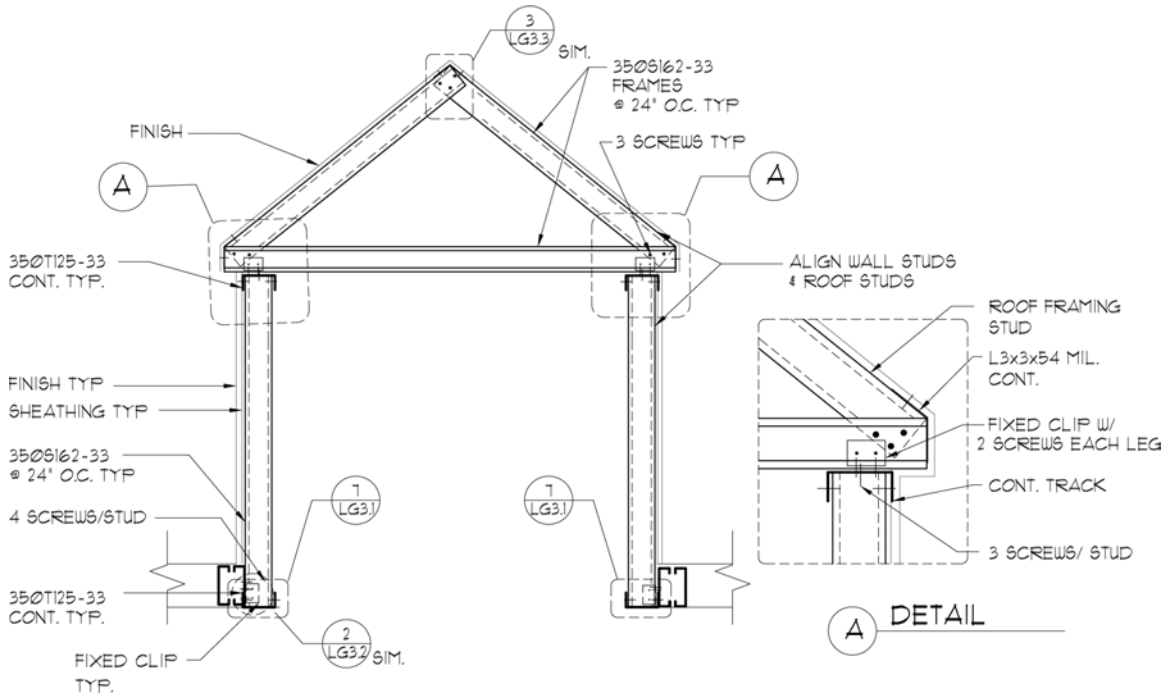


Figure A-13 Dormer section (detail)

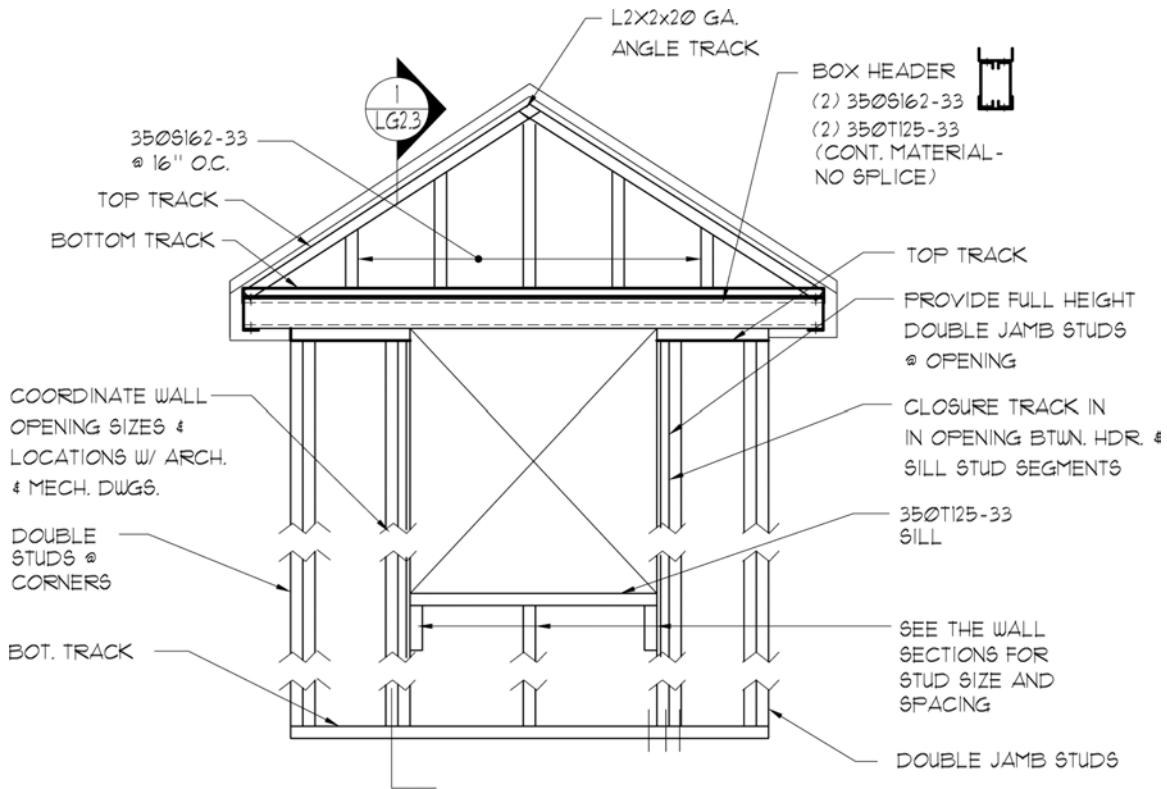


Figure A-14 Opening elevation at dormer

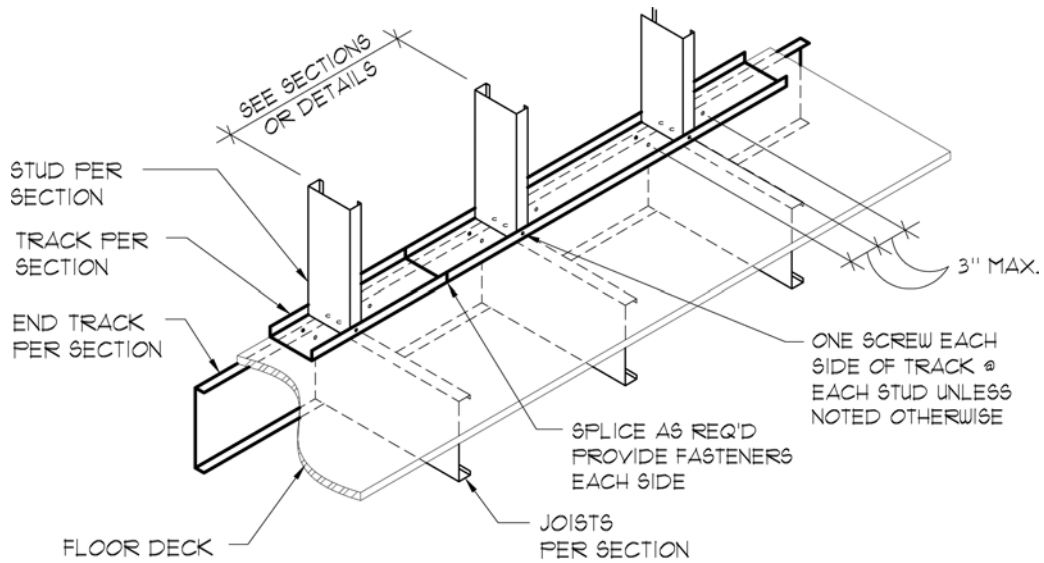


Figure A-15 Typical track-to-stud connection detail

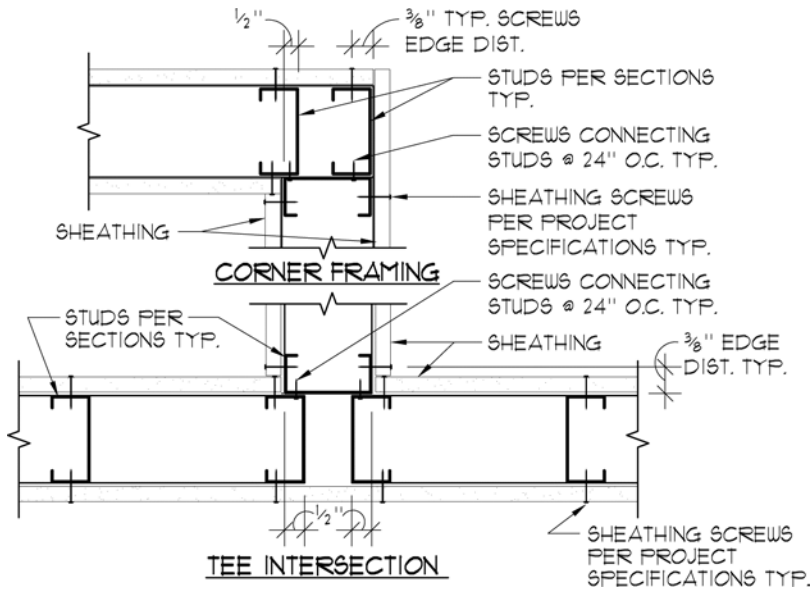


Figure A-16 Typical corner wall details

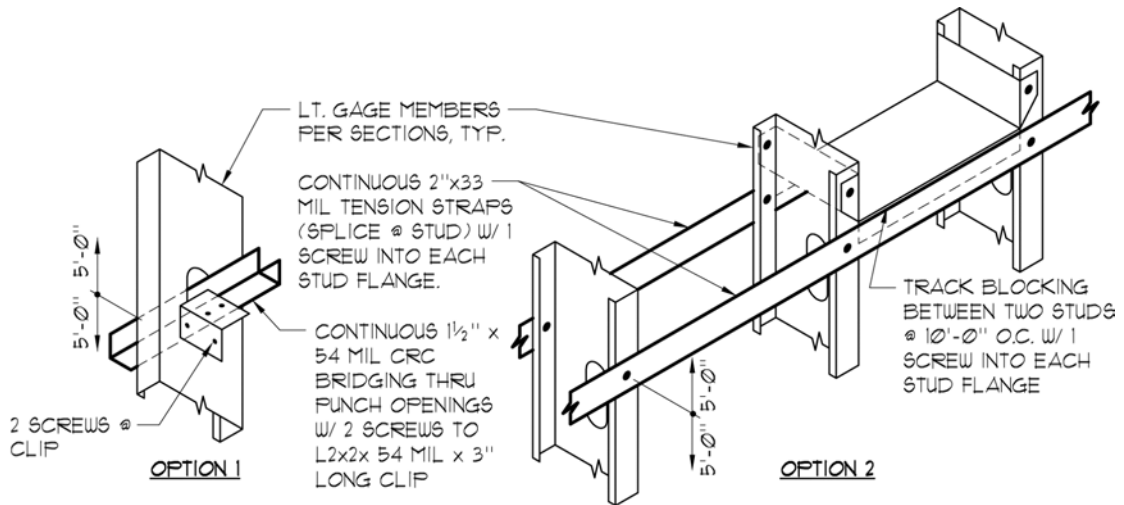


Figure A-17 Typical stud and rafter bridging details

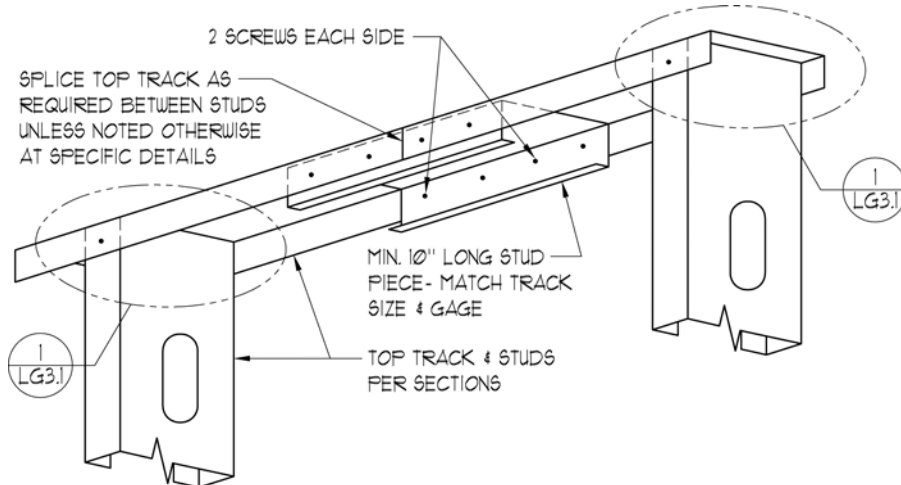


Figure A-18 Typical unsupported track splice detail

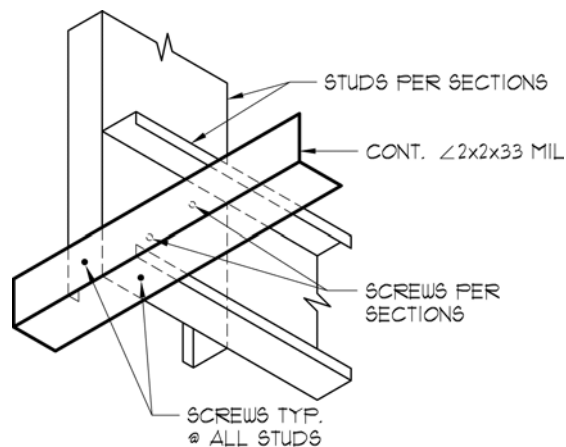


Figure A-19 Typical bulkhead connection detail

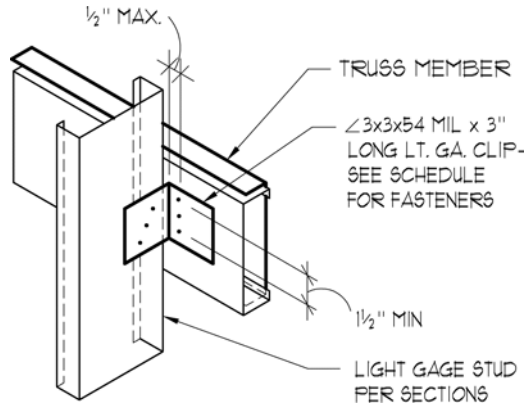


Figure A-20 Typical connection detail

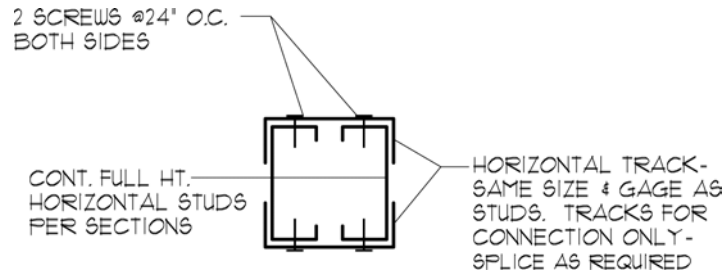


Figure A-21 Typical box beam detail

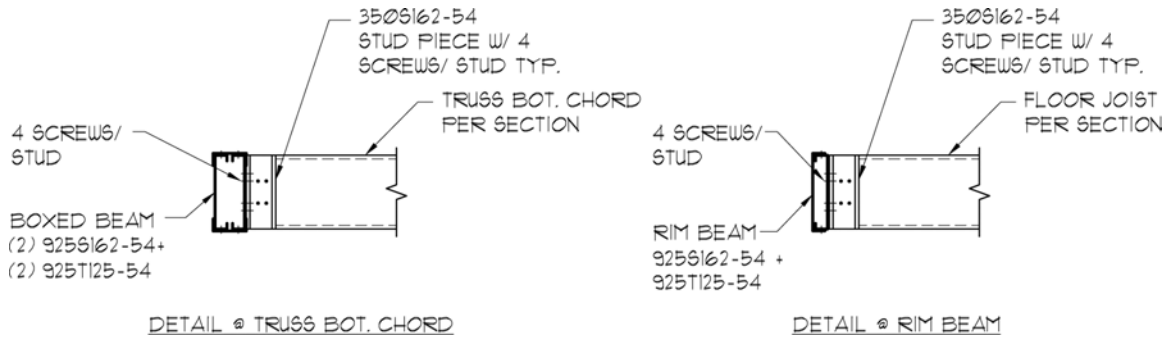


Figure A-22 Typical beam connection detail

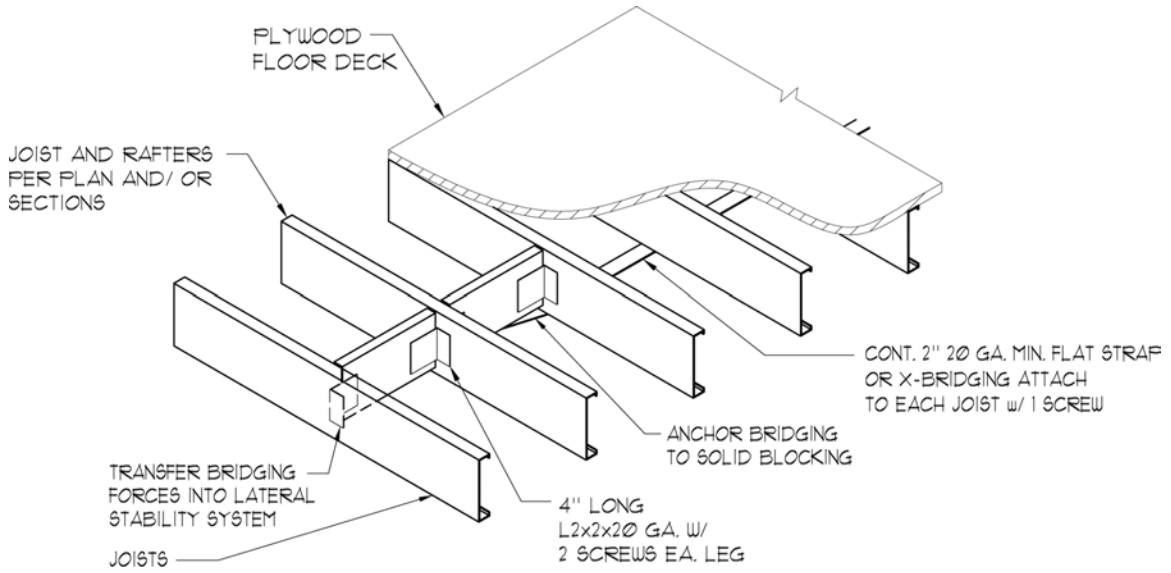


Figure A-23 Typical floor bracing detail

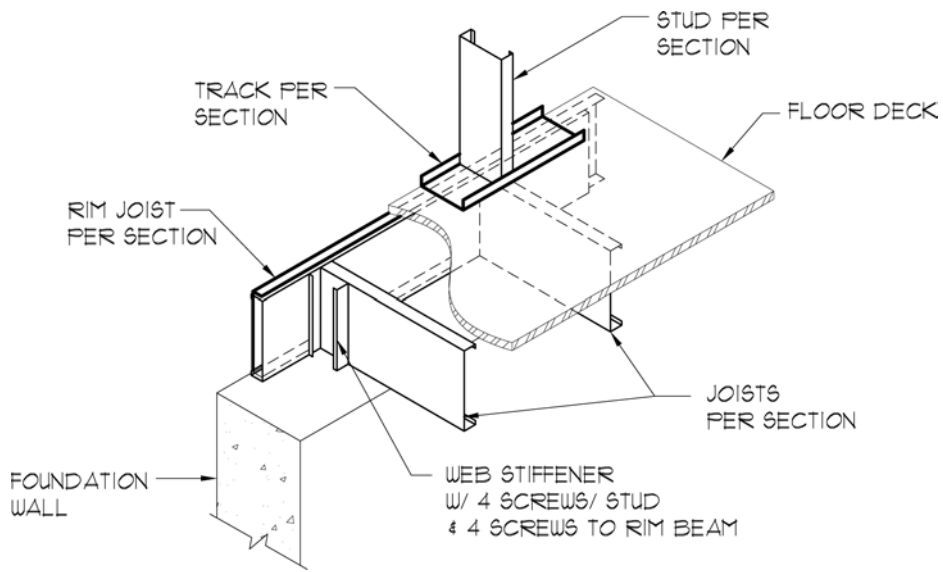


Figure A-24 Typical rim joist connection detail

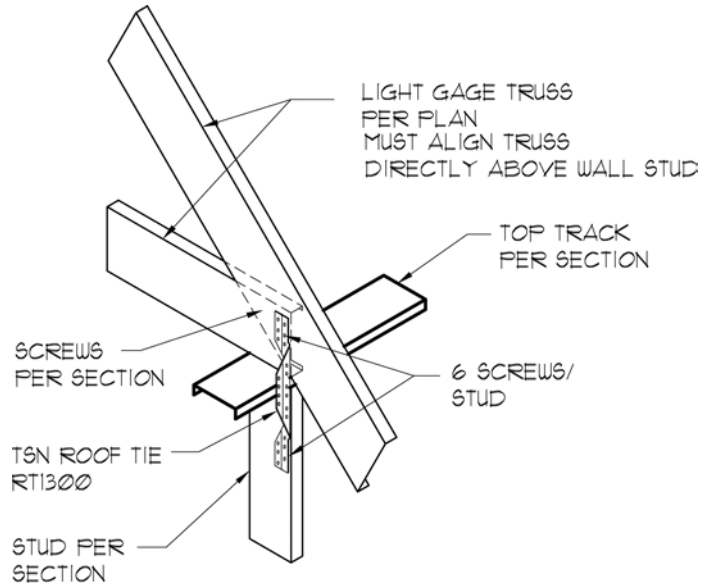


Figure A-25 Typical roof truss connection detail

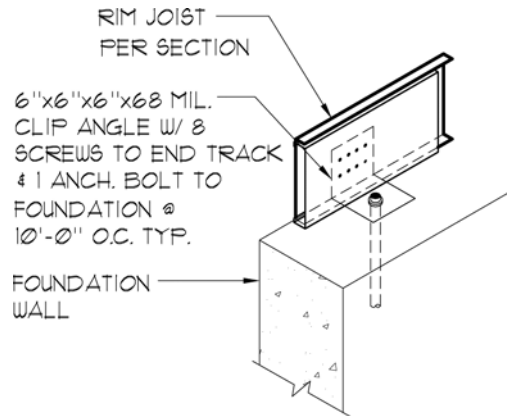


Figure A-26 Typical foundation edge detail

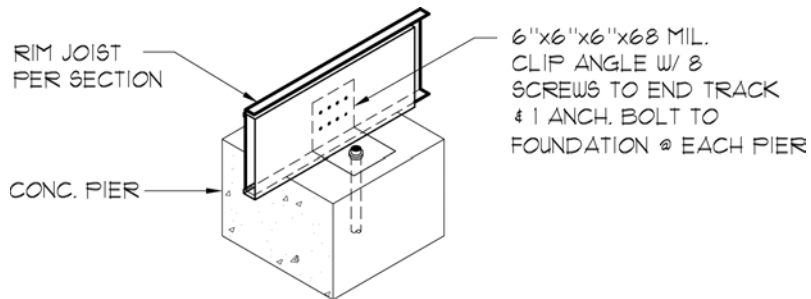


Figure A-27 Typical detail at pier

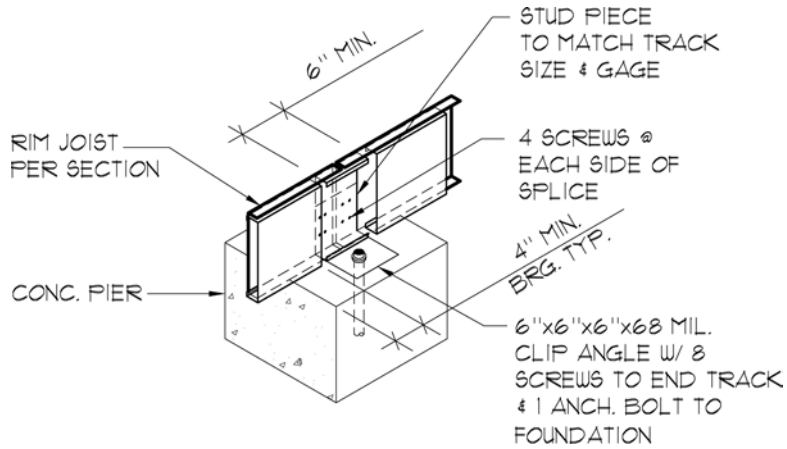


Figure A-28 Typical rim beam splice detail

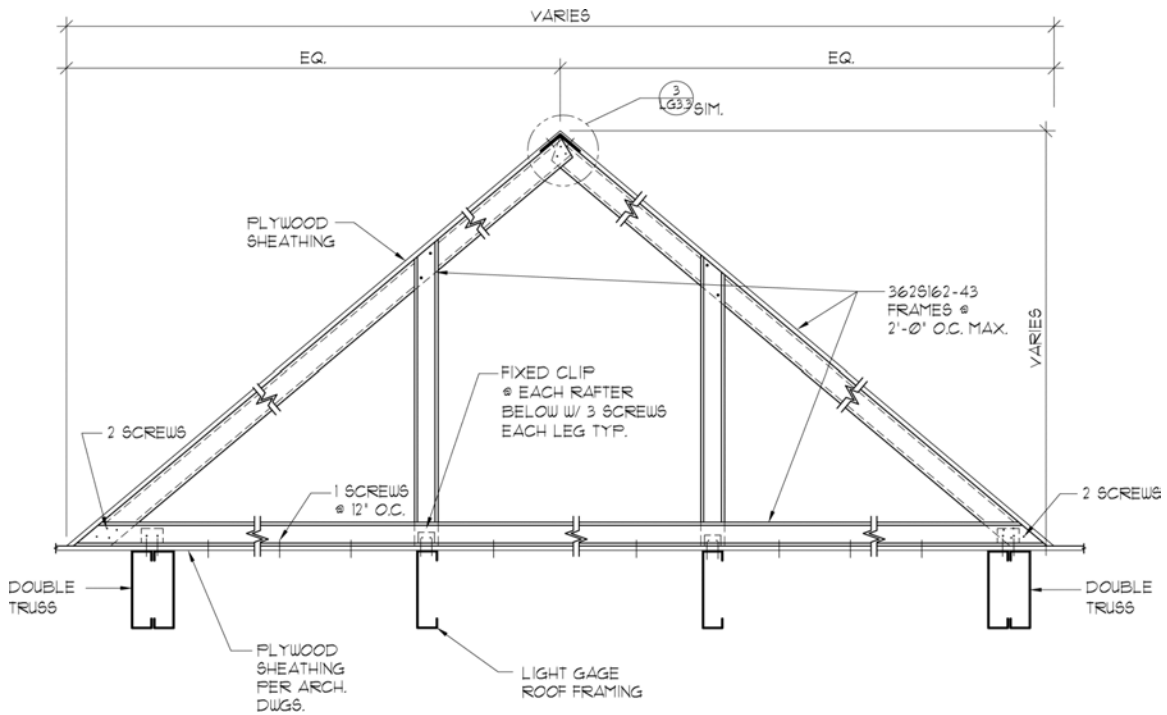


Figure A-29 Typical overbuild frame detail

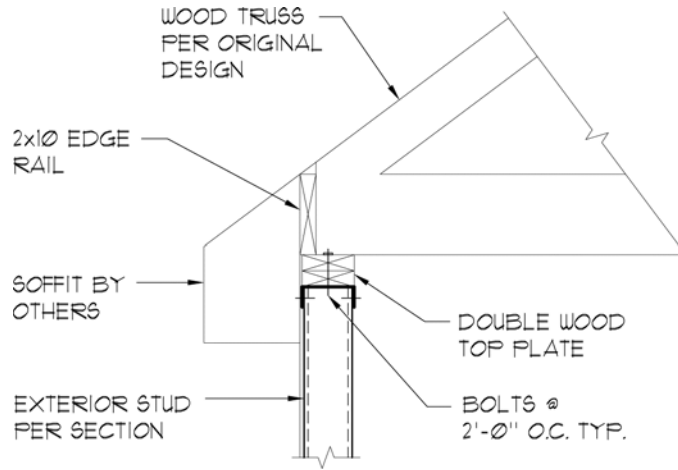


Figure A-30 Optional wood truss connection detail

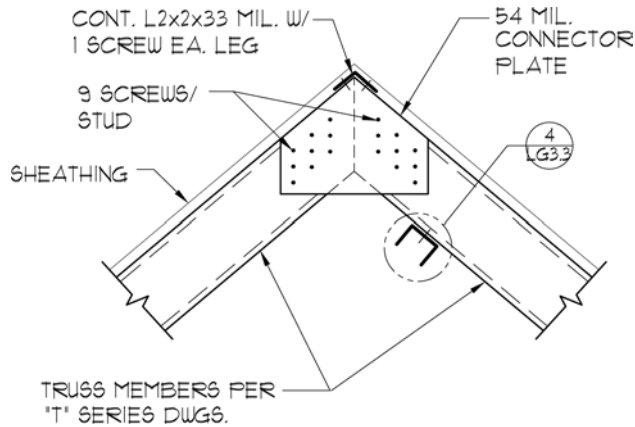


Figure A-31 Typical truss connection detail

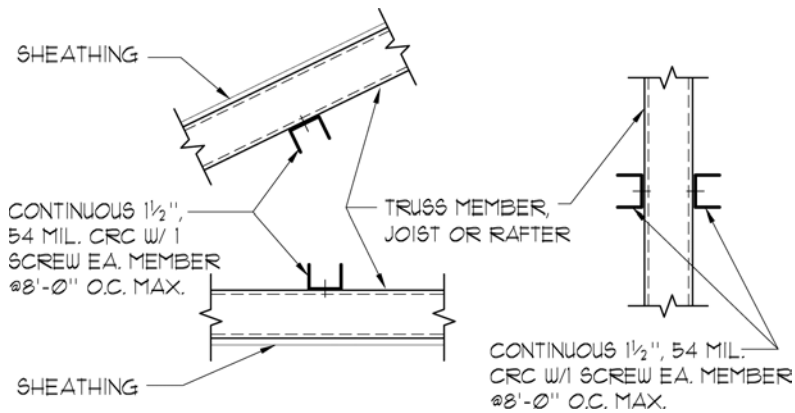


Figure A-32 Typical truss bridging details

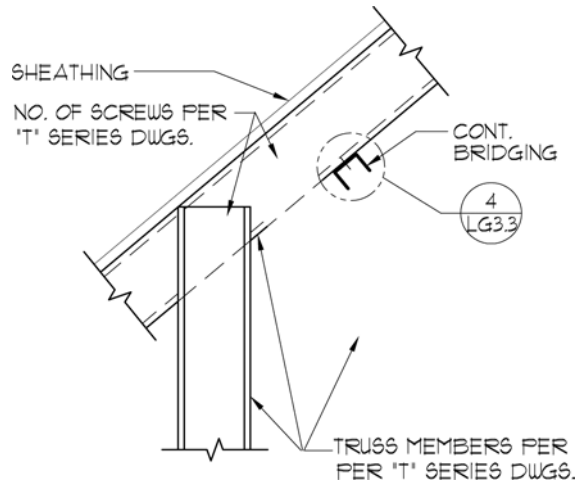


Figure A-33 Typical truss connection detail

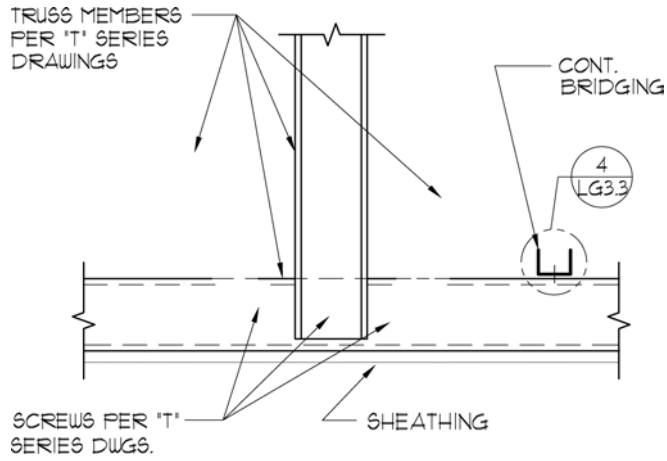


Figure A-34 Typical truss connection detail

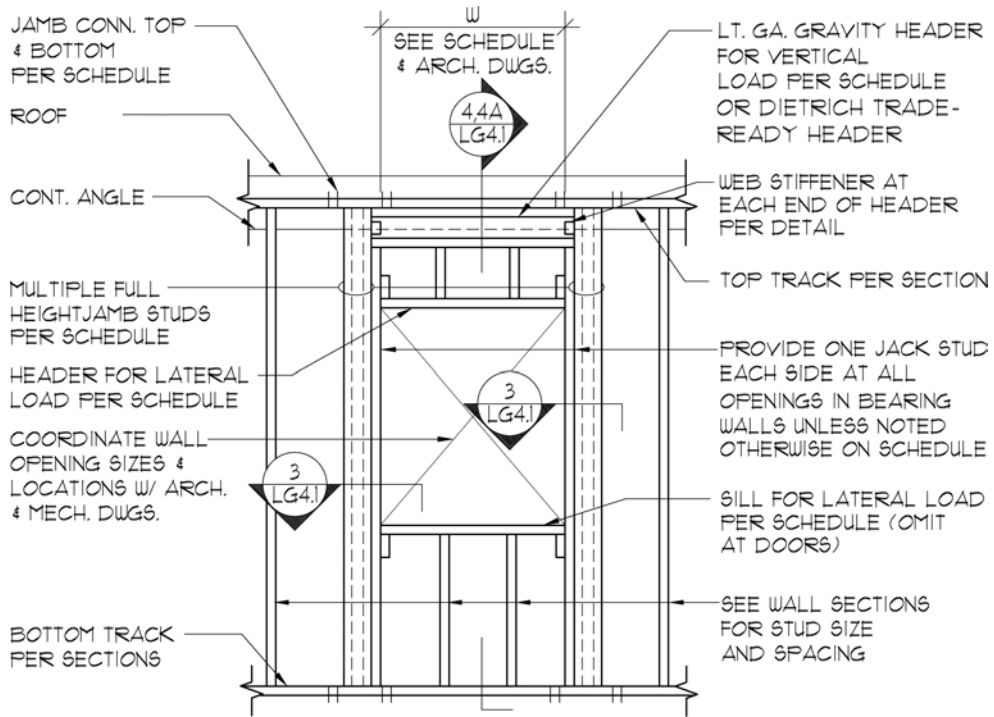


Figure A-35 Typical exterior light-gage bearing stud elevation at opening

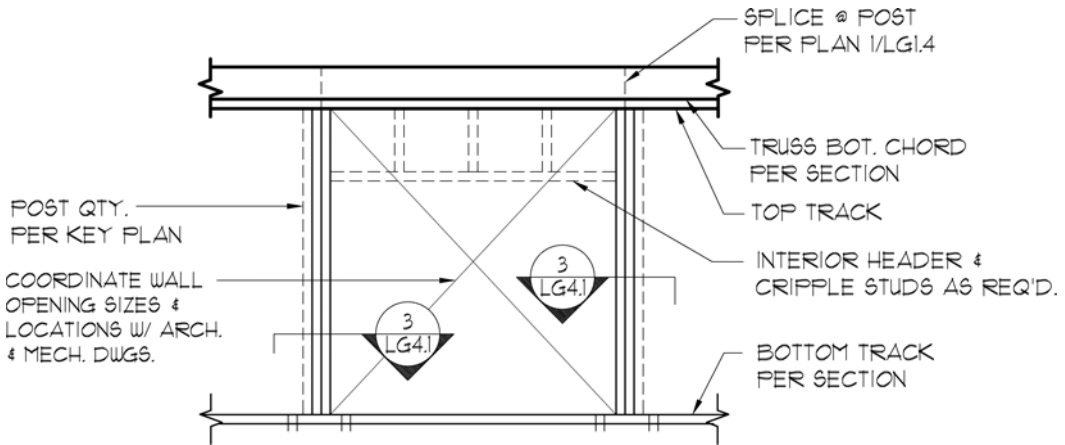


Figure A-36 Typical interior light-gage bearing stud elevation at opening

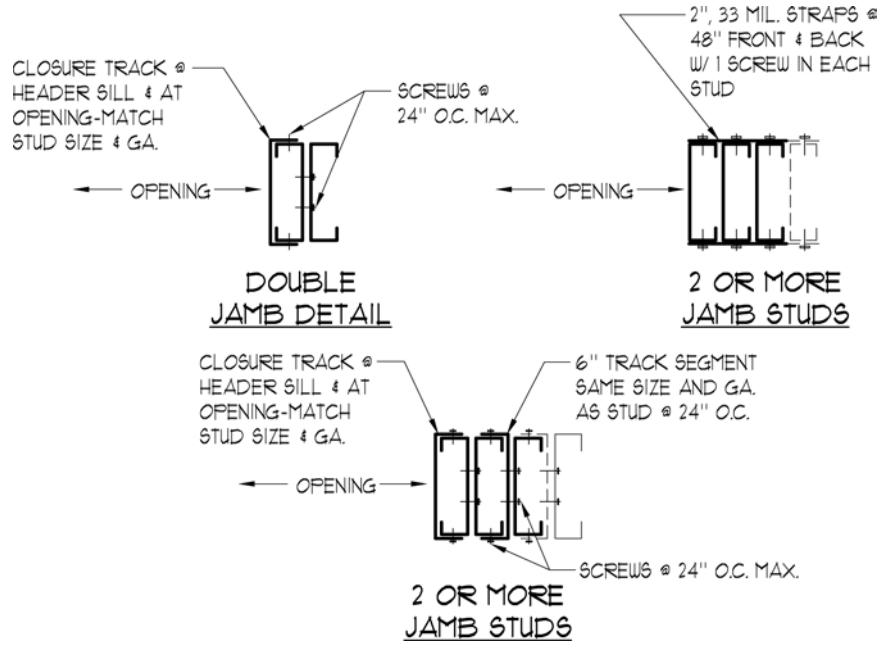


Figure A-37 Alternate jamb details

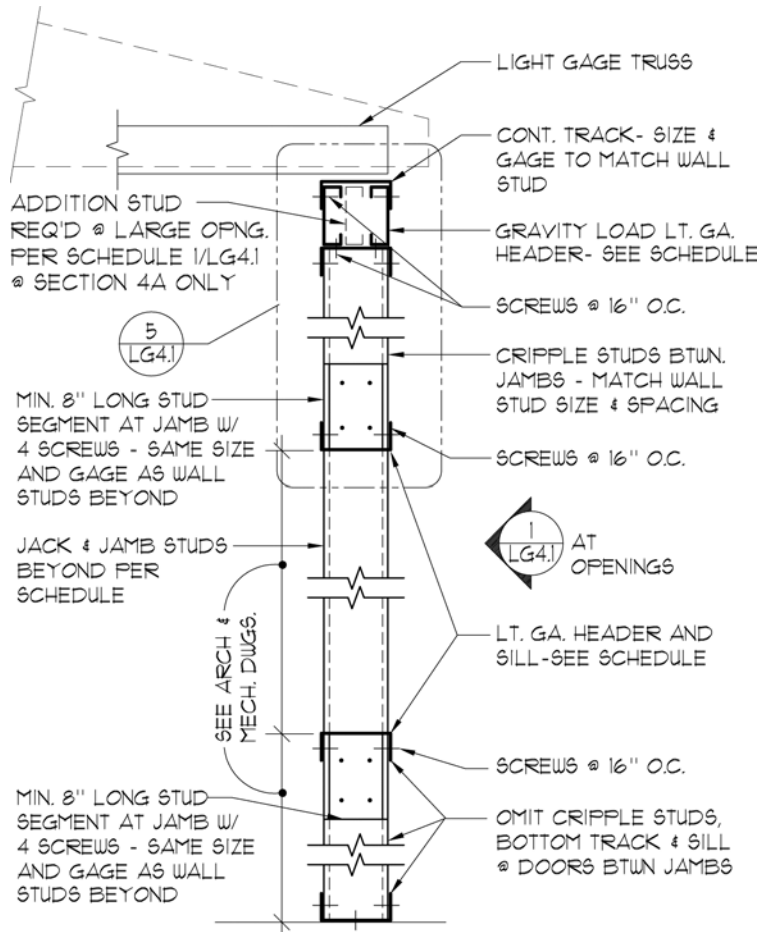


Figure A-38 Typical bearing wall opening section

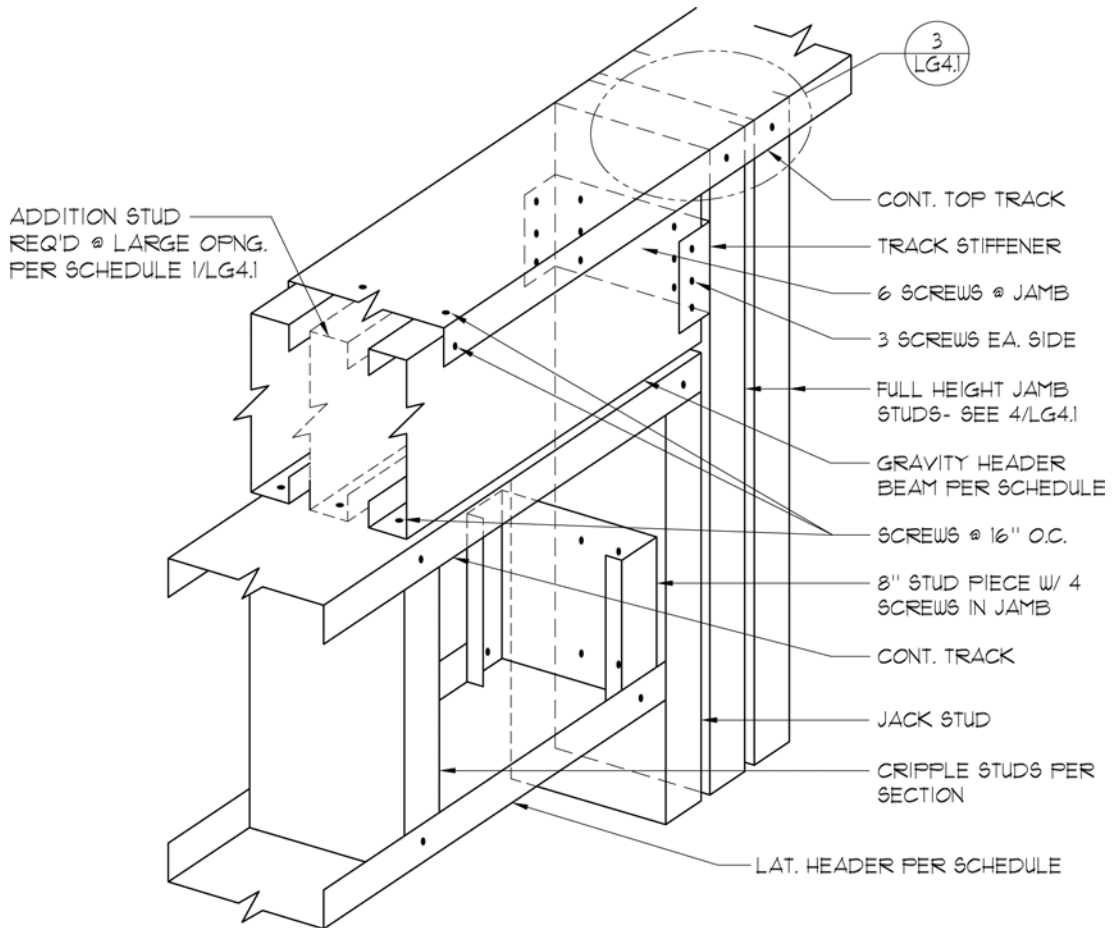


Figure A-39 Header to jamb connection detail

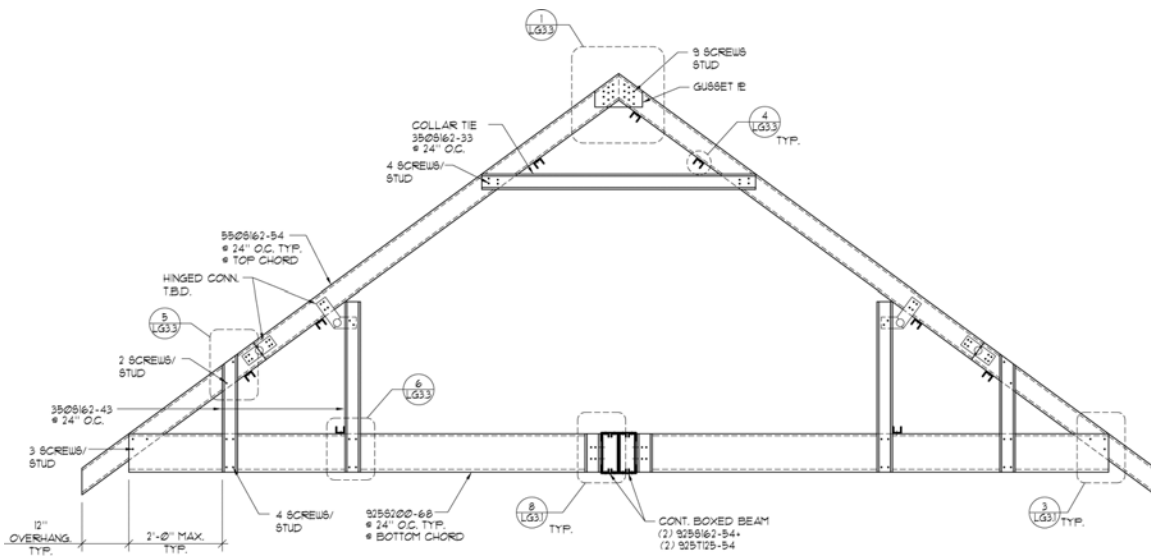


Figure A-40 Truss section

APPENDIX B

RESOURCES

Organizations serving this market:

Steel Framing Alliance

1201 15th Street, N.W., Suite 320
Washington, D.C. 20005
(202) 785-2022
FAX: (202) 785-3856
www.steel framingalliance.com

Description: The Steel Framing Alliance (SFA) serves the full spectrum of companies and individuals that make up the steel framing industry by providing market data and statistics, education and training programs, information and tools on construction, design and applications, research and testing, and informational and marketing programs to support the development of the steel framing industry. In addition to direct development and delivery of these programs, the SFA sponsors or works in close cooperation with other key organizations within the steel framing and construction industries.

Key contacts: Larry Williams, President
 Janice Duncan, Membership

Steel Stud Manufacturers Association

8 S. Michigan Avenue
Chicago, IL 60603
(312) 456-5590
FAX: (312) 580-0165
www.ssma.com

Description: The Steel Stud Manufacturers Association (SSMA) is comprised of companies that fabricate studs, track, channel, joists, and connectors used in steel framed construction. Together, members of the SSMA produce nearly 80 percent of all metal studs in the United States. The SSMA provides technical support and published design guides and engineering details for engineers and architects, as well as maintaining technical specifications and standards for the cold-formed steel studs.

Key contacts: Augie Sisco, Executive Director
 Don Allen, Technical Director, (202) 263-4488

Center for Cold-Formed Steel Structures

Butler-Carlton Civil Engineering Hall
University of Missouri-Rolla
Rolla, MO 65409
(573) 341-4481

FAX: (573) 341-4476
<http://web.umn.edu/~ccfss/>

Description: The Center for Cold-Formed Steel Structures is the nexus of technical and design information for the cold-formed steel industry, providing educational programs, design guides, technical services, and research. Two unique programs offered by the Center include the Short Course on Cold-Formed Steel Design, the industry's most intensive technical educational program, and the Cold-Formed Steel Specialty Conference that provides experts from around the world with a forum for sharing information and ideas about cold-formed steel elements and design. The Center serves as the industry's central reference library for research and technical documents.

American Iron & Steel Institute

1140 Connecticut Avenue, N.W., 7th Floor
Washington, D.C. 20036
(202) 452-7100
FAX: (202) 452-6573
www.steel.org

Description: The American Iron & Steel Institute provides the underpinning of the industry's design and construction standards through its maintenance of the cold-formed steel framing specification, its ANSI-accredited design standards, and implementation of these documents through the building codes.

Key contacts: Helen Chen
 Jay Larson, (610) 691-6334

Information and resources on a full-spectrum of steel framing subjects can be obtained as follows:

Business Planning Information

- Data and statistics on the residential and commercial framing industries.
- Updates on new product developments, services, and industry news
Source: Steel Framing Alliance
Contact: Larry Williams
American Iron & Steel Institute
Contact: Jay Larson

Engineering and Design

- Seminars and educational programs
Source: Center for Cold-Formed Steel Structures
Contact: Roger LaBoube
Steel Framing Alliance
Contact: Maribeth Rizzuto
- Directory of Engineers / Architects
Source: Steel Framing Alliance
Contact: Janice Duncan
- Technical inquiries

Source: Center for Cold-Formed Steel Structures (design and specifications)
Contact: Roger LaBoube
Steel Stud Manufacturers Association (stud and track characteristics)
Contact: Don Allen
NAHB Research Center / Toolbase Hotline (general inquiries)
(800) 898-2842

- Engineering Details
Source: Steel Framing Alliance
Contact: Janice Duncan (also available at www.steel framingalliance.com)
Steel Stud Manufacturers Association
Contact: Augie Sisco (or www.ssma.com)
- Codes and Standards
Source: American Iron & Steel Institute
Contact: (202) 452-7100 (or www.steel.org)

Training and Education

- Builders / Framers
- Code organizations / local jurisdictions
Source: Steel Framing Alliance
Contact: Maribeth Rizzuto
- Publications
Source: Steel Framing Alliance
Contact: Janice Duncan (or www.steel framingalliance.com)

Sourcing material, tools, equipment

Source: Steel Framing Alliance
Searchable online directory at www.steel framingalliance.com

Manufacturing, Technology, Research, and Innovation

Source: Steel Framing Alliance

The SFA has two teams that evaluate, prioritize, and manage research programs that are identified by members and others in the industry. All research is directed to resolve a technical or construction-related barrier, advance the development of building standards, or provide information needed to capitalize on market development opportunities. Publications and results are made available in the form of design guides and standards, seminars, and research reports.

Contact: Jay Larson, American Iron & Steel Institute